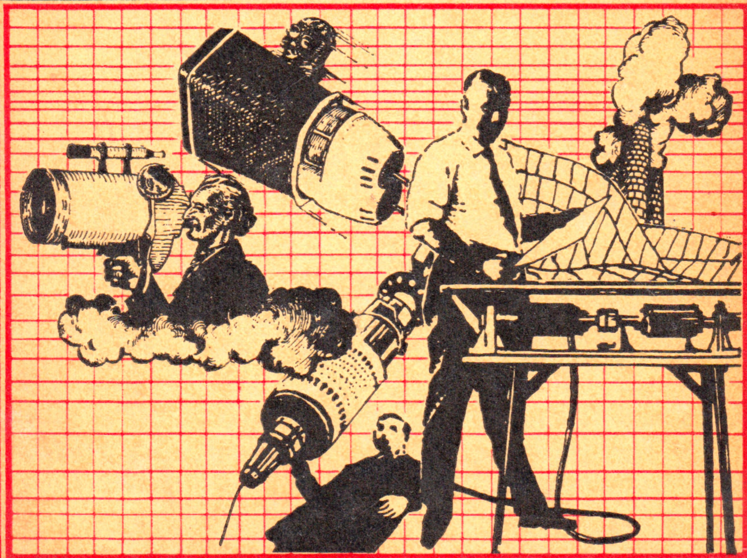
Machines of the 20th Century

Mir Publishers

Moscow

ИЗДАТЕЛЬСТВО · МИР ·



E. Muslin

ИЗДАТЕЛЬСТВО · МИР ·

Е. Муслин

МАШИНЫ XX ВЕКА

Идеи, конструкции, перспективы

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Machines of the 20th century

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Contents

Preface

Although machine building has been a branch of human activity for centuries, only in the 20th century have machines begun to assume such in all-important role. Machines provide us with food and clothing, treat for illnesses, build our houses, convey us from place to place and even help us to think. The machine is devised by man to utilize forces of nature, to facilitate manual and intellectual labour and increase productivity, to relieve man, partially or completely, of the burden of manual labour and the ever-increasing number of intellectual problems. In short, machines have become the mechanical servants of mankind.

New machines are being designed to deal with a manifold of new problems which continually arise in modern industry. The Soviet Union alone produces more than 130,000 types of machines annually, this figure is increased annually by another 2000.

It is quite impossible to cover the whole subject of machinery within the scope of one small book. Bearing the above in mind, the author undertook the task of bringing into light only the most characteristic trends, of citing certain curious examples and of describing some specific engineering solutions. From the immensity of problems facing today's engineering world, he

only selected those which, at the time the book was being written, appeared to be the most important, urgent and stimulating. The author, for the most part, wrote about machines he had personally seen, and scientists and inventors he had met, plants and designing offices he had actually visited.

This helps the author to make the story more interesting, but also put certain restrictions upon him, limited his choice of subjects and confined the narrative to the area he has explored. That's why the book deals largely with the Soviet machines.

In short, the author has tried to describe the greatest possible number of original principles, and some unusual and even paradoxical designing solutions, rather than attempt an exhaustive work on the subject. It must be left to the reader to compile a comprehensive picture from these scattered bits of information.

And although written in a popular scientific style, the present work is neither concerned with spectacular spaceships heading for far-away planets, nor with "nautili" exploring the depths of the ocean; it mainly deals with such modest unassuming hard workers as rolling mills, excavators, lathes, presses and turbines which make up the machinery backbone of the present-day industry.

1. Materials – Flesh and Blood of Modern Machines

Each new step in the development of engineering is always accompanied by the appearance of new materials. The above may be also stated quite the reverse: new materials facilitate the development of engineering. Both statements are equally correct. If highly durable metal alloys had not been developed, there would be no modern rockets and aviation today. And rocket engineers, in their turn, stimulate metallurgists to produce new alloys. Half a century ago the phenomenon of superconductivity was discovered, this was used to generate superpower magnetic fields and currents, which, in turn, gave a powerful impetus to research work. As a result, we have today thousands (!) of different superconductive alloys at our disposal. Urging one another, metallurgy and machine building are advancing simultaneously.

When laymen speak of new engineering materials they refer mainly to their increased strength. Those better informed may also mention higher corrosion resistance, better workability and improved coefficients of friction or thermal conductivity. These are, however, only a small portion of the virtually unlimited variety of properties which mechanical engineering materials may already possess or are expected to acquire.

Mechanical strength, elasticity and thermal conduc-

tivity are undoubtedly of primary importance to a designer. Therefore, metallurgists and technologists fight persistently to avoid superfluous weight and improve the existing alloys by selecting the optimum processing conditions: heat treatment, pressure forming methods, etc. At times they are lucky to make a major break-through. As a result, the prefixes "high", "super" and "hyper" come into use: we speak of high-strength, super-heat-conductivity, super-plastic and hyper-elastic materials. Each of these prefixes give new perspectives to mechanical engineering and the use of these materials often makes it possible to improve machines' parameters by a whole order.

Another, less traditional trend in contemporary studies of materials consists in imparting to materials "alien" properties which are in no way associated with them. We know, for instance, that glass is transparent, that metals conduct electricity, that iron is ferromagnetic, and that rubber withstands enormous deformations without being destroyed. Now, what if we had transparent steel, electrically conducting wood, a metal as stretchable as rubber, or a rubber with magnetic properties? At first sight this seems impossible. Yet, such materials already exist. Moreover, superhigh pressures have made it possible for pure oxygen and carbon dioxide to be transformed into solid matter at room temperature. A titanium and nickel alloy has been produced which, metaphorically speaking, possesses "memory": one may twist, bend and hammer parts made of this alloy, but once heated, they resume their original shape.

We have grown accustomed to operate with homogeneous materials which possess the same properties in every direction throughout their volume. And now we have already entered the era of anisotropic, multilayer and reinforced materials. Reinforced concrete is the most

commonly used material of this kind. Over the past years, we have seen the advent of plastics reinforced with ceramic fibres, cardboard and paper interwoven with steel threads, aluminum sheets coated with heat-resistant films, etc.

Finally, specialists in engineering materials have taken a new approach to the problem of the permanent nature of materials' properties. This far, it has been taken for granted that the properties of a material always remain constant, i.e., are absolutely stable. Of course, we are not going to deny the advantages of an alloy which is never subject to fatigue, or of a plastic which does not fade in the sun and whose structure does not change. Yet, it is no less useful to have materials whose properties can be changed and controlled. Imagine an alloy strong and durable in use, but soft as clay in processing; or glass with variable transparency or a variable refractive index; electric conductors with controllable conductivity; materials with variable porosity, elasticity and thermal conductivity. This is not only a future horizon; many materials of this type already exist and are being employed in today's engineering.

It is clear that the number of combinations of all kinds of original trends in the synthesis of new materials is practically unlimited. This, in turn, opens new realms for the designing of still cheaper, effective and unthinkably perfected, compared to what we have today, machines and mechanisms.

2000 TIMES STRONGER THAN STEEL

Prof. A. Stepanov, a Leningrad physicist, has proved that materials may exist whose properties are as superior to those of diamond as diamond is superior to carbon

Until recently, the strength of the finest thread-like crystals known as "whiskers" had, what was thought to be, the uttermost limit of material strength. Can there be such a limit? Of course not, for that would contravene the philosophical concept of the inexhaustible nature of matter and its properties.

In fact, while specialists in the practical use of new materials had only begun to master their work on whiskers, theoreticians were already paving the way for new scientific advances. We are speaking, in particular, about the work of the Leningrad physicist, Prof. A. Stepanov of the A. Joffe Physico-Technical Institute under the Academy of Sciences of the USSR. Prof. Stepanov demonstrated that there can be materials whose mechanical properties are many times superior to those of diamond just as diamond is superior to carbon. Here we speak about hypothetical crystals having what is called close-packed structures.

It is well-known that most solids have cristal structures. In such structures atoms are distributed in a definite order forming crystal lattices.

These lattices infinitely differ, each substance having its own specific lattice. Different lattices are characterized by the different density of packed atoms given by coordination numbers. The coordination numbers show how many "neighbours" each atom has in its crystal. Diamond and silicon, for example, each, have four "neighbours". In principle, the greater the coordination number, the stronger is the substance. As a matter of fact, the exact quantitative relationship between the atomic structure of crystals and their physical and chemical properties remains for the while unknown. In future, when this problem is solved by science, we shall actually be able to produce substances with predetermined properties. At present, we are only able to make qualitative evaluations which, neverthelles, are

of great help in explaining the properties of materials and denoting their improvement.

We know that crystal lattices of most substances are packed more or less loosely. With the aid of methods developed by solid-state physics, Prof. Stepanov attempted to predict the properties acquired by carbon, nitrogen, hydrogen, oxygen and some other substances if these formed close-packed crystals with the coordination number 12, consisting of face-centred cubic structures.

Is is possible to obtain such crystals? Judging from the state of science today, it would be unwise to give a flat negative answer to that question. On the contrary, in a number of cases, for example with respect to carbon, it is already possible to answer this question positively.

Prof. Stepanov's basic concept lies in determining the limiting, in the light of our present-day views, characteristic of substances. He assumed that the bonds in close-packed structures were homogeneous and did not differ, so far as their values were concerned, from atomic bonds in molecules of the same substances in their gas phase. Prof. Stepanov assumed that the least distance between atoms in his hypothetical crystals was equal to the equilibrium distance between them in an isolated diatomic molecule.

Proceeding from these assumptions and making use of the well-known crystal lattice formulae, Prof. Stepanov calculated the Debye temperatures, bulk moduli and other parameters of the hypothetical crystals. After this it was easy to calculate, by using the empirical approximating formulae, the expected melting temperature, density and strength of these crystals. Calculations showed that the close-packed modified carbon would make a real "super-diamond" far superior to the ordinary diamond as the latter is superior to common

salt. The expected density of the super-diamond is believed to be 7.6; strength, 40,000 kg/mm^2 (about 30 times higher than that of iron whiskers); melting point, 23,000°C.

Still better results are to be expected of hydrogen, oxygen and sulfur, although strange as it may seem, nitrogen appears to be able to break all records. The close-packed nitrogen structure is expected to have a density of 25, an amazing refractoriness with a melting point as high as 80,000°C and an incredible strength of 280,000 kg/mm^2, which is 200 times stronger than whiskers and 2000 times greater than the best structural steel. These figures have nothing to do with science fiction: they were mentioned in the journal *Solid-State Physics* published by the USSR Academy of Sciences. It is true, that so far these figures are nothing but a forecast by a theoretician concerned with determining maximum limits rather than with finding concrete ways of attaining these limits.

Who can deny that Albert Einstein's famous formula establishing the mass-energy relation also pointed to the maximum limits (in this case, the power-producing limits) of matter? Originally a mere abstraction, that formula paved the way to the mighty atomic power engineering of today. D. Mendeleev, too, spoke of hypothetical elements which ultimately became a fact. The negative solution of Dirac's equation which suggested the existence of antielectrons for some time was regarded even by physicists as a fruitless quest, but only four years later the antielectrons were discovered in the form of positron.

Finally, let us recall the high theoretical strength of ordinary crystal structures predicted forty years ago. The values mentioned by scientists at that time were regarded by many as unattainable. Today the ultrahigh-strength whiskers seem nothing out of the

ordinary to engineers who are only concerned with putting them to practical use.

Apparently, the most feasible way of obtaining close-packed structures is by using superhigh pressures and temperatures. They must be many orders higher than those obtained at present in laboratories or found in any part of the Universe. In all probability, this may be the reason why such structures have not yet been discovered in nature. Incidentally, it was reported that in a number of countries scientists have successfully accomplished the polymerization of oxygen by explosive compression, so that it remains solid at room temperature.

What advantages do we gain from ultrahigh-strength and super-refractory materials having close-packed structures? Is it worth trying to overcome enormous technological obstacles in order to obtain such materials?

Certainly! These new structures would unrecognizably change and improve our life; they would cause a new technological revolution the consequences of which are difficult to imagine. First of all, at one stroke mankind's power resources would be doubled or trebled: the efficiency of all heat engines would approach 100 per cent, as it would be possible for designers to use higher temperatures that today seem unthinkable. The motors could be made far lighter and more compact, since not only their efficiency, but also their specific output would be raised by several times.

Steam boilers, turbines and electric generators would give way to simpler and more effective magnetohydrodynamic generators. At present, mass employment of such generators is largely hampered by a shortage of heat resistant refractory materials.

The most fantastic possibility of constructing earth-ships that could penetrate the Earth's crust and cruise

freely across oceans of molten magma would become a reality. Spaceships would be able to fly close to the Sun and even enter its upper photospheric layers whose temperature is as "low" as 6000°C.

The utilization of temperatures and pressures several times higher than those attained today would sharply intensify all processes in chemical technology. Ultrahard materials would render ploughs, cutters, shears, etc. practically unweariable.

Television towers and antennas could be miles tall. Man would be able to build a "sky elevator", a gigantic cableway to a space terminal orbiting as a stationary Earth's satellite 36,000 km away. Such a project was considered several years ago by Yu. Artsutanov, a young Leningrad scientist, who calculated that materials required for this project must have a strength of 1500 kg/mm^2 and a specific gravity no greater than that of water. Close-packed hydrogen crystals exceed the above requirements by almost ten times! Similar elevators on the Moon, Mars, asteroids and other celestial bodies of the solar system would allow interplanetary communication on a large scale by using the free rotational energy of celestial bodies.

This project was further developed by a group of American scientists whose findings were presented in the journal "Science". It is the opinion of specialists, that the cosmic lift project ranks second and follows K. Tsiolkovsky's theoretical contribution on cosmic rocket transport. And now, the new ultrahigh-strength materials are helping this project to come true!

We could spend endless time discussing similar ideas, but perhaps it will be enough to stress just one more point. The improvement in mechanical properties of materials and design of high-pressure presses has already resulted in the synthesis of artificial diamonds and such ultrahigh-strength materials as borazon

and elbor. These, in their turn, will help us to obtain still harder and stronger materials. The close-packed structures will, doubtless, do the same: they will open up new opportunities for creating still harder and stronger structures owing to the greater changes in the character of atomic bonds.

STEEL AS SOFT AS WAX

Academician A. Bochvar discovered superplasticity of metal alloys

The past years have seen an increasing employment of the "warm stamping" process. A blank is heated to 500-800°C. No scale is produced at that temperature, thermal strain is negligible, but the compression stress is reduced 2 to 4 times, as compared to cold stamping. This enables the strongest materials to be worked without shortening the die life. Only one condition is to be observed: metal must not be stamped at the instant of phase transformation, i.e., when the structure of its crystal lattice is being rearranged.

You will read in any book on stamping that pressure forming of metals is inadmissible during the phase transformation process, as the blank may simply disintegrate. In physical metallurgy, such an opinion was commonly recognized in the thirties.

In 1945, Academician A. Bochvar observed a curious phenomenon. At the phase transformation temperature a zinc-aluminium alloy became as soft as clay. The metal stretched better than rubber, so that short bars made of this alloy elongated into long thin threads. Dr. Bochvar called the phenomenon "superplasticity". Since then, this astonishing phenomenon has been closely studied by many Soviet and foreign scientists. Superplasticity has been detected in a great number of metals and alloys, both ferrous and non-ferrous, and

even in ceramic oxides. Why, then, is it almost never used in industry? Because the superplasticity stage, which mainly coincides with phase transformation, is extremely difficult to detect: it occurs over a very short period of time and within an extremely narrow range of temperatures; moreover, that range is never stable, but shifts up and down all the time.

To catch the actual phase transformation instant is impossible, but the changes in physical properties which accompany that process can be detected. For instance, the rearrangement of the crystal lattice pattern is accompanied by an abrupt change in magnetic permeability. Ya. Okhrimenko, D. Sc. (Tech.), and O. Smirnov, an engineer, both of the Forging-and-Stamping Faculty of the Moscow Steel and Alloy Institute, took the advantage of this phenomenon. They made an instrument which measured the magnetic permeability of a blank and connected it to the starting device of a press. When the phase transformation begins and the blank becomes superplastic, an electric pulse actuates the press. The instrument is very simple in design; the female die, made of a non-magnetic material, has a ring groove containing two concentric windings. These windings and the blank make up a sort of a transformer: electric current passing through one of the windings induces current in the other, the current being proportional to the magnetic permeability of the material of the core, i.e., of the blank.

A blank, whose temperature is slightly above the upper limit of the phase transformation temperature, is placed in the female die. As it cools, the crystal lattice reforms and the metal changes its state from paramagnetic to ferromagnetic. At this instant, a sudden change occurs in the magnetic permeability and, consequently, a change in the current through the secondary winding. The sensitive bridge circuit comes out of balance and

the press is actuated at once. Thus, stamping takes place precisely at the instant of phase transformation, irrespective of cooling conditions, variations in the chemical composition and lattice structure of the blank.

This joint invention by Ya. Okhrimenko and O. Smirnov (USSR Inventor's Certificate No. 207,678) was the first successful attempt to use superplasticity for practical purposes which spelt a future rapid development of pressure forming techniques. The use of superplasticity reduces several times the required power of presses and makes it possible to process bigger blanks. In addition, processing allowances are reduced so that less forming operations are needed to manufacture the most complex-shaped parts.

It is interesting to note the methods of processing austenitic steels extensively used in boiler and turbine manufacture. The tremendous hardness of these steels makes their cutting and stamping an extremely difficult process. Unlike carbon steels, austenitic steels are not hardened by heating, but by cooling with liquid nitrogen. Now, if phase transformation takes place at a subzero temperature, superplasticity will also occur at that temperature. Consequently, austenitic steels can only be formed at subzero temperatures. Without doubt, this may radically simplify processing technology and improve working conditions, as blazing, smoking furnaces can be replaced by noiseless refrigerating machines or Dewar flasks containing liquid air.

A PLASTIC MATRYOSHKA* AS A REDUCTION GEAR

A plastic reduction gear 5 times lighter and 10 times cheaper than a metal one. A gear ratio of 2,000,000

* Matryoshka is a popular Russian toy. It is a set of wooden dolls that fit compactly one into another.

Ernest Renan, an outstanding French philosopher and historian of Christianity, said that a person's intellect is clearly seen from one's attitude towards the puppet theatre. The most naive and foolish look at the performance with open mouths. The unsophisticated understand all in the scene and take in all good faith. Those who are a little more clever notice how the actors activate the dolls by strings. They feel insulted by the illusion and loudly express their indignation. They do not enjoy the show and, what is worse, spoil other people pleasure. Finally, the really clever ones, although they clearly see the manipulation of the strings and note some minor faults, do the show justice and enjoy it, for they realize that there can be no peak of perfection in art or life.

It is often appropriate to remember this amusing parable when the conversation turns to plastics. The credulous general reader enthusiastically, excessively and avidly swallowing the off-hand reports of the miracles of technological progress met in the popular science literature, sincerely believes that soon we shall need neither metal, nor bricks, nor reinforced concrete. Locomotives, cars, houses, everything will be made of plastics.

Those better informed, designers, engineers, foremen, are quite sceptical about plastics. Tell your plastics tales to the marines, they would say. Handles, buttons, soap-boxes, shaving-mugs—that's what your plastics are good for. Save metal all right, but no good for essential parts, you know. No question about that.

Finally, there is a third group (alas!—not so many) who know perfectly well that, although plastics give way to metals in strength, have a high coefficient of expansion, a low elastic modulus and an unfortunate susceptibility to moisture absorption, can, when properly used, not only replace metals, but also surpass them in

many respects. Plastics are unrivalled for their lightness, cheapness, corrosion resistance and ease of processing.

"The pros and cons of plastics must be considered at the very beginning of designing, instead of attempting to mechanically replace steel parts by plastic ones. This is a basic error that today restricts mass introduction of new materials into machines. It is time to understand clearly that a plastic structure is absolutely different from a steel one" was voiced by Miron Konstantinovsky, an inventor of original and highly promising varieties of wave reduction gears (USSR Inventor's Certificates Nos. 168,969 and 179,151). Owing to the exceptional simplicity of manufacture, compactness and cheapness these reduction gears can be effectively used in different branches of industry and agriculture.

Initially, all was due to a dish-washing machine. At that time, M. Konstantinovsky was employed by NIItorgmash, a Moscow Institute which designed new machines for the catering industry. The Institute was commissioned to design slot-machines and automatic equipment for snack-bars. A dish-washing machine appeared to be a hard nut to crack. Dirty dishes passed between rotating nylon brushes cleaning the dishes of grease and leavings. After some time, the brushes became coated with grease and to wash them periodically, an additional device had to be added. But what if that device, too, became greasy? That was a vicious circle; it seemed that the machine's dimensions would grow endlessly. Then Konstantinovsky suggested that the brushes be replaced by a powerful water jet, rushing from slotted injectors. The dimensions of the machine returned to normal, and it at once became obvious that the worm reducer transmitting movement from an electric motor to a dish-moving mechanism was large and cumbersome. The power requirements were small, but the

coupling sleeve, worm, bearing casing, bulky oil bath, and the massive steel frame all combined to make the machine unnecessarily big and heavy. At this stage Konstantinovsky remembered wave reducers that had just been invented.

A wave reducer was first patented in 1959 by Ch. V. Masser of the United States (US Patents Nos. 2,906,143 and 2,931,248). Before then, designers the world over took it for granted that all gear wheels were to be rigid. Their teeth could be of different form: oval, elliptical or triangular, but the form should remain constant. Ch. V. Masser bravely disregarded this age-old dogma and used a deliberately deformed gear as a means of transmitting movement, which led to the wave gear with its amazing properties. The operating principle of this reducing gear can be explained in a few words.

In its simplest form, the gear contains three basic parts. Imagine an ordinary gear rim, a rigid ring with internal teeth. Inside this is a second gear which is a thin flexible ring having similar teeth. Inside the inner rim, there is a wave generator comprising a plate with two planetary-rotated rollers. The rollers expand the inner rim, making it elliptical and force its teeth to mesh with the internal teeth of the outer rim. Suppose the plate rotates clockwise. Rotation of the rollers produces two deformation waves running along the flexible rim, as if counting the teeth. Let us assume that the outer rim has 102 teeth, and the inner one, 100. Then, after one revolution of the plate with the rollers, the inner rim that has two teeth less than the outer one, is turned through the length of these two teeth, but this time in the opposite direction. Therefore, this rim will make one complete revolution after 50 revolutions of the plate, which means that the gear ratio of the wave reducer is 50. The ratio may be raised by increasing the

number of teeth on both rims. It is much more difficult to attain the same result with ordinary gear wheels. To begin with, we shall need several pairs of them, secondly, the gear diameters would be very large, for they are directly related to the pitch of the teeth determined by the torque. The greater the torque, the greater the bending force acting on the teeth, and the greater the tooth pitch required. As for the torque, it increases with the same power as the reciprocal of the number of revolutions. So it is clear now why the low-speed machines of the past had such big gear wheels. As one thing depends upon another, we obtain a snowball effect, as the transfer ratio increases. This is because the force in an ordinary gear is transmitted almost by one tooth which is engaged even if the gear had a thousand teeth.

In a wave reducer, many teeth are continually engaged, therefore the force that acting upon each tooth is comparatively negligible. This is why, small teeth are capable of transmitting large torques.

A further advantage of a wave reducer is that it can transmit movement through leaktight and slightly deformable walls. This is of utmost importance for nuclear power stations and the chemical industry, where even a minute leakage of radioactive or toxic substances is impermissible. There may be a great variety of different types of wave reducers. We may make stationary not the outer rim, but the inner one, or the plate with the rollers. We may employ a greater number of gears and make them work differentially, etc. There is a wave reducer, for example, just a little more complicated than the one described above, which ensures an astronomical gear ratio of 2,000,000! It seems unlikely that such a ratio can be obtained by any other means. Isn't it strange, then, that with all their qualities, wave reducers are almost never used? This may be only explained by conservatism or ignorance on the part of designers,

moreover, the production of flexible metal gears is quite a complicated matter. The surface of the teeth has to be hard, otherwise they are easily worn. At the same time, tooth stress concentration areas must be avoided otherwise the continuous deformation waves will inevitably produce fatigue cracks. It is extremely difficult to find a metal which can long endure such conditions.

M. Konstantinovsky was perfectly aware of all this and decided to test plastics. He reasoned that plastic gear rims would be cheap and easy to manufacture. Then, stresses in the teeth of wave reducers were small, and the relative sliding speeds of tooth surfaces were negligible, so a plastic reducer must be quite effective. Yet Konstantinovsky had to overcome a considerable obstacle. The heat conduction of plastics is on the average 250 times lower than that of steel, and their strength sharply reduces with a rise in temperature. As a result, heated plastic gears easily break up. There were two ways out: to minimize evolution of heat and accelerate its abstraction. M. Konstantinovsky and several other designers succeeded in solving the problem, which at once made plastic wave reducers absolutely practicable.

In short, it was like this. The small rollers were replaced by large eccentrics. This increased the deformation radius of the flexible wheel, contacting area and efficiency. In addition, steps were taken to additionally reduce heat evolution and finally, a corrugated metal band was immersed in the oil bath, leaving its ends outside the bath. The band proved to be an excellent cooler, and the reducer was no longer overheated. During this time, M. Konstantinovsky had become Head of a Department introducing new materials at the Ministry of Petrochemical Engineering. This industry needs a host of different controlling valves, shutters and other fittings which may be operated from a central

control panel. Each valve assembly needs its own electric motor, reducer and control unit, i.e., a whole set of units.

One factory in Tula alone turns out scores of thousands of such sets annually. Each set weighs 35 kg, while the electric motor only accounts for 5 kg of that weight, the remaining 30 kg being the weight of the reducer. It was decided that the latter be replaced by a plastic wave reducer.

The Moscow automatic heat engineering plant manufactured test equipment, and a wave reducer was tested for 400 hours under maximum load. The reducer weighing only 5 kg had gears made of polyamide-68 and stabilized cord capron successfully withstood the tests which, in fact, had been too arduous. According to specifications, the reducer is only required to operate for two hours a day. Actually, it was used continuously and still was not overheated. This meant that for short operating periods, it was capable of transmitting a far greater power. In fact, even metal wave reducers, with regard to heating, are strong enough to withstand loads which are 30-40 times higher than those permitted in continuous operation. Since almost all the parts of the new reducer were made of cheap plastic and require no additional processing, the cost of the mechanism has dropped some ten-fold. It only weighs 10 kg of which the electric motor accounts for one-half. The resulting gains are tremendous, and yet the new reducer has not generally been introduced into industry.

The inventors then constructed another plastic reducer with a gear ratio of 2800 for an actuating mechanism metering the supply of steam to turbines employed at thermal power stations. Its advantage over the previously used double-reduction worm gear lies in the utmost simplicity of the wave reducer. A worm reducer requires a cast casing of an intricate configura-

tion, with shaft bores set at right angles to one another, to say nothing of difficulties and time required for producing worms and gear rims. Bores have to be machined with utmost accuracy, otherwise the gears will not work properly. The reducer must be also provided with a big oil bath, because with such a low efficiency, 12 per cent (!), almost all the transmitted power is transformed into heat. To sum up, a double-reduction worm reducer is quite a cumbersome machine. A wave reducer, on the contrary, is a compact and elegant device, its gears fitting one into another like wooden "matryoshkas", occupying very little space. Almost all its parts, with the exception of some screws and standard ball bearings, are cast of plastics. So far as their shape is concerned, these are all bodies of revolution, so press moulds for them may be made on any lathe. True, to improve heat abstraction, the casing is also made of metal, and this is not a complicated affair either, being simply a length of pipe. The wave reducer is 4 times more efficient than the worm reducer, its efficiency may even approach 50 per cent.

What can we infer from the foregoing? Soviet inventors have developed and successfully tested extremely simple, light and cheap wave reducers produced from commonly used plastics. The gear ratio of one step in such a reducer amounts to 400 and the efficiency, to 80 per cent. The transmitted power under continuous operation conditions reaches 2-3 kW and the output torque, up to 100 kgm.

Such reducers are extensively used in kitchen appliances, washing machines, potato peelers, kneaders, accessory drives of machine-tools and automatic lines, looms, pulley blocks, hand electric tools, etc., i.e., in all types of machinery where transmitted power is small and where large gear ratios and reduced weight are essential. These reducers may be particularly advantage-

ous in agriculture, at cattle ranches and in irrigation pipelines where mechanization is impeded by the high cost of electric drives. Collective farmers usually reason that it is more rational to distribute forage by hand than to pay 60 to 80 roubles for a reducer. Cheap reducers will find extensive application in agriculture.

The reducers described may be still far from the peak of perfection, but they are already in use. When the heat conductivity of plastics is improved, the power of plastic reducers may be further increased and, hence, their field of application extended.

Work is also under way on an electromotor-reducer which will not have any fast-rotating armature. The magnetic field will play the role of a wave generator, whereas the output shaft of the motor will rotate at an extremely low speed. For compactness such a motor-reducer should break all records. The absence of fast-rotating parts will ensure its effective operation even under the conditions of colossal accelerations and dynamic loads that would break down any conventional reducer.

1000 TIMES THE HEAT CONDUCTION OF SILVER

Thin pipes with porous filler—a new constructional material possessing superheat-conductivity

A group of engineers recently witnessed an unusual experiment in a research laboratory. One end of a long bent rod was heated by an electric arc, while its other end was put into a tank containing cold water. In an instant, the rod became glowing red, and the water started boiling. Those present raced to the place. No one had seen it before, it was unbelievable. It seemed that a Gulf Stream of heat rushed into the water through the long metal rod. Even if it had been made of copper

or silver, which display the highest heat conduction, the heat flow would have been a thousand times less.

When the rod had cooled, it looked like carbon steel, nothing out of the ordinary, and the experiment was not meant to deceive. The explanation was found inside the hollow rod, in the filler of the "thermal pipe".

The problems of delivery and abstraction of heat face engineers every day. The nuclear reactor at an atomic power station, for instance, releases enormous amounts of thermal energy which has to be immediately converted into electricity. On the other hand, electric motors, internal combustion engines, electron tubes or rockets soaring into the sky are always menaced by overheating. To avoid this, there must be an effective means for heat abstraction. Little wonder that heat engineers have been racking their brains over decades in an effort to accelerate the slow pace of thermal flows. Yet, the extremely low heat conduction of natural materials seemed to be an unsurmountable obstacle. Let's take copper, for example. To transmit as little as 10 kW of thermal energy through a copper rod less than 50 cm long and with a diameter of 2-3 cm, tremendous "thermal head" is needed. One end of the rod would have to be heated to a temperature three times higher than that of the Sun's surface, which would vaporize the copper. At the same time, the other end of the rod would have to retain room temperature. It is impossible, even keeping in mind that copper is one of the best heat conductors. Meanwhile, a "thermal pipe" of the same dimensions is capable of transmitting the same amount of energy almost without resistance, so practically, no difference can be detected between the temperatures at its ends. Only an enormous copper bar weighing 40 tons and having 3 m in diameter could possess similar heat conduction.

The idea of a "thermal pipe" was first brought forward by American engineer Richard Gogler as far back as 1942, during World War II. Nobody seemed to pay any attention to it at that time. The invention had been on the shelf for more than two decades, until recently, when George Grover, a Los Alamos physicist, attempted to utilize it. The construction of a "thermal pipe" is very simple. It seems unbelievable that such amazing results can be attained with a means that simple. The "thermal pipe" is just an ordinary hollow, thin-walled evacuated pipe with its ends sealed. Its inner walls are lined with some porous material, for example, baked ceramics, cord fabric or spun glass, which, in turn, is impregnated with some volatile liquid. As we heat one end of the pipe, the liquid at that end evaporates, and the resulting pressure difference forces the vapour to the opposite end of the pipe. Here the vapour is condensed and gives up its heat to the cold walls, after which the liquid rushes back through the capillaries to the heated end. In most liquids the latent heat of vaporization, which breaks molecular bonds, is very high and during the condensation process this heat is fully recovered, therefore the intensity of the heat flow in the pipe surpasses all expectations. As we have already said, the liquid returns to the heated end of the pipe through the capillaries of the composite material. This is where the simplicity and reliability of the system lie. In this case, neither pumps, nor additional power sources are necessary. The only force acting is that of capillary attraction due to surface tension between the molecules of the liquid. Capillary attraction is independent of any external factors, including the force of gravity. For that reason, a thermal pipe can operate under any conditions, both on our Earth and in space.

Apart from its fantastic heat conduction, it possesses

other amazing properties. These make it possible to concentrate thermal fluxes and change or maintain at a preset level temperatures of machines and technological processes just as effectively as electronic engineers have long been controlling currents and voltages in their circuits or as mechanical engineers have recently started to control forces, energies, strains and other impact parameters. It is not by chance that engineers refer to the thermal pipe as a "temperature transformer" or a "thermal semiconductor". Calories and degrees become as controllable as volts, amperes and kilograms.

Let us now consider this situation: we have to maintain a predetermined constant temperature over a substantial area. Such problems are often met during heat treatment of components, in chemical reactors where complex technological processes require absolutely stable conditions, or when drying heat-sensitive materials. Take, for instance, varnishes and paints. Once you slightly overheat or overcool some portion of a varnish or paint coating, cracks will appear. Banknote paper is another example. To make it durable and avoid mouldering while in circulation, the paper is impregnated with special substances. After that, the successful drying is wholly dependent upon maintaining the temperature exactly at a prescribed level. Until recently, the job was done by complicated automatic devices. Now it is sufficient to use a thermal pipe for the purpose, shaped as a furnace hearth, air heater of a drier, etc. Heat may be obtained from any source, which may be even a wavering free flame, and the thermal pipe transmits the heat energy in an absolutely even manner. This is because the temperature over the entire surface of the pipe is constant, being governed completely by the absolutely constant evaporation and condensation temperatures of the heat carrier, i.e., the working fluid. Thus, temperature fluctuations in an energy source only

affect the intensity of evaporation. The thermal pipe is an ideal isothermal regulator for any technical application, sometimes the most unexpected. Let us take, for example, a steam turbine with a capacity of 600,000 kW. It takes several hours to start such a turbine. A solemn technical ritual must be observed which seems as complicated as the traditional tea-drinking ritual of the Japanese. The essential thing in this process is to make sure that the heavy rotor is heated as uniformly as possible. Once the temperature of some portion of the rotor is slightly raised as compared to the rest of it, the huge shaft sags, the blades strike the stator, and the turbine is put out of action. The only way to avoid an accident is to heat the rotor as slowly as possible. As a result, power engineers find themselves tied hand and foot, unable to change capacities freely over a period of time required for starting the huge steam turbine. They often have to use during peak demands less economical gas turbines which may be quickly started. However, if the rotor shaft is made as one huge thermal tube, it will always be heated uniformly.

This is not all. Heat may be supplied to one end of the tube over a pin-point area and removed from a larger area, or vice versa. This does not affect the amount of evaporated fluid. By changing the ratio between the heat input and output areas we can either dissipate or concentrate the thermal energy and freely intensify or reduce the thermal flux per unit area. The tube will act as a "heat transformer". Now, as everybody knows, a transformer can link up originally incompatible power sources and consumers; in our case, the incompatibility of the source and the consumer stems from the striking difference in their thermal conducting properties.

Foreign scientific journals cite a number of interesting examples of the utilization of heat transformers. At

one time it was commonly believed that radioactive isotopes were inapplicable in cosmic apparatus because of their low heat radiation density. Today, scientists working at Cape Kennedy regard them as highly promising sources of energy, as the concentration of thermal energy has become a simple matter.

Another case in point. A spaceship darts into a planet's atmosphere at the second cosmic velocity. The leading edges of the ship's wings immediately reach a temperature of thousands of degrees and start melting, whereas their side surfaces are only slightly warm. This is reminiscent of a meteorite whose surface is white-hot, while the temperature inside it is less than the freezing point of water. Such a difference in temperatures often splits and destroys meteorites. This could also happen to spaceships. And if the inner surface of a wing is coated with a porous material and impregnated with a fluid, this will eliminate the danger of thermal shocks and cracks, the excess heat will now dissipate through the entire surface of the wing, not only through its sharp edge.

Similar problems exist on earth. For example, the anodes of radiotransmitter tubes radiate so much heat that air-cooling proves inadequate to dissipate it. The job is done by noisy powerful blowers. Here, a thermal tube easily removes the heat and reduces its density to a required limit or, in other words, distributes the heat over a large area, from where it is easily removed by conventional fans.

The introduction of power lines made unnecessary the rigid connection between sources and consumers of electric energy and rendered them territorially independent of one another. To a certain extent, this is also true of thermal tubes. For instance, to make nuclear power station economical, it is of utmost importance to remove the heat energy as far from the reactor as pos-

sible, to a place where there is practically no radiation. Thermal tubes are the most convenient for this work, for they rule out any losses of energy.

If a thermal tube and the capillaries are made of dielectric substances and an appropriate working fluid is selected, we shall obtain a device that happily combines high heat conduction with high insulation properties. Thus, the most complicated technological problems related to the cooling of powerful electric motors, generators, high-voltage plants, etc. should be easily solved.

The work on thermal tubes is still in its research stage, but experiments have already shown that they are equally effective at the freezing point of water and at the steel melting point. They are capable of conducting thermal fluxes of scores of kilowatts and acting as the working fluid may be a host of different substances: water, methyl alcohol, acetone, some molten metals, such as caesium, potassium, sodium, lead and bismuth, or non-organic salts, etc.

Due to their simplicity, reliability, unsurpassed lightness and compactness, practically unlimited service life and ideal self-regulation, thermal tubes are sure to find extensive application in all fields of technology. They may be used at plants for direct conversion of energy, in spaceships, in medicine, chemistry, electrical engineering, and even in all kinds of household appliances. Thus, we shall find them in light, capillary-cooled automobile engines of the future, in kitchen stoves, in central heating systems where they will maintain a constant temperature in all sections of a building irrespective of the story height, etc.

Several types of thermal tubes have been already patented. It is only natural that their inventors work in the most advanced fields of technology: aviation, space exploration and atomic power engineering.

In July 1967, Frederick Burggraf and Archie Horald Peruggio of the General Electric Company in America were granted US Patent No. 3,334,685 for a vane with three built-in thermal tubes. The tubes remove heat from the incandescent edge of the vane and transfer it to its centre which can be cooled in a conventional way, by a circulating liquid. Such a design makes it possible to substantially raise the gas inlet temperature and thus increase the efficiency of turbojet engines.

The only force that makes the fluid in a thermal tube move along the capillaries is surface tension, i.e., molecular attraction. Thus, the thermal tube needs no external sources of energy. Now, if there is a source of energy close by, why not use that energy? This thought may have prompted Ralph M. Singer, an American engineer, to invent his own version of a thermal tube for which in October 1967 he was granted US Patent No. 3,344,853. According to his invention, the surface of a tube is coated with a dielectric, while the tube itself contains a fluid that conducts electricity. The tube is placed in a powerful magnetic field. As a result, electric current is induced in the fluid, and forces appear which accelerate the fluid's circulation along the walls of the tube. The inventor insists that a magnetic field may raise a tube's thermal conductivity almost three-fold, making the porous filler unnecessary. However, what is still more important, this is a new, convenient method of regulating thermal processes. To speed up or slow down these processes, only the magnetic-field intensity need be changed.

A different solution to the problem has been found in Belgium. Belgian inventors have displayed much ingenuity in simplifying the thermal tube to the utmost. Their version of the tube, which was granted Patent No. 3,402,764 in September 1968, needs neither magnetic field, nor a porous filler because the capillaries

are replaced by fine longitudinal grooves made on its inner surface. This tube is not affected by vibrations or overloading, for there is nothing in it which may break down or deteriorate.

This far, thermal tubes are in their infancy, but there is a growing effort to utilize them in all fields of technology where heat is involved.

CHROMOPLASTIC AND CHROMOPLASTICITY

A material which becomes lighter in colour when stretched and darker when compressed

Any structure or any of its elements have to withstand loads, so it is absolutely necessary that the resulting strains produce no harmful effects.

Designers calculate the greatest value of the safety factor, which would ensure the durability of a building, machine or assembly without making it too large, heavy or excessive material consumption. However, there is no way of accurately forecasting the time, place and manner in which a plastic deformation occurs in an element under load.

An ingenious solution to this problem has been found by a group of Rumanian scientists. The group, headed by Academician Stefan Belan, included Prof. Sandu Reutu, D. Sc. (Eng.) from the Mechanics of Rigid Bodies Research Centre of the Rumanian Academy of Sciences, Valeriu Petku, D. Sc. (Eng.) from the Scientific Research Institute of Construction Engineering and Building Economics, and engineer N. Goldenberg from the Chemical Research Institute. Their method has become known in Rumania and abroad as "chromoplasticity".

Previously, practical testing was based on the degree of change in metal crystallization when subjected to

loads. This method is, however, so complex, that at present it is only used to illustrate some hypotheses. For investigations of plastic deformations, the Rumanian scientists suggested, that plastic materials be used and paid their attention to plastics which become lighter in colour along a bend. In fact, that was not exactly what they had been looking for, because the change in colour only showed a zone of stretching and gave no indication of the degree of deformation.

Chromoplastic is a coffee-coloured material whose colour intensity changes under different loads. In the stretched zones it is almost white, and in the compressed zones, nearly black.

Thus, one can easily detect the order in which zones of plastic deformations appear and find out the loads corresponding to each stage of the deformation. Chromoplastic is also very cheap.

The practical implementation of the new method is quite simple. First, a model of a structural element is made which is, say, 1/50 of the actual size. The load is also reduced by 2500 times in accordance with the similarity rule (2500 is the square of 50).

The new method may be effectively used by designers employed in civil engineering, ship-building, aircraft-building, machine-building industries, etc.

WING MADE OF BALLS

Structures with controlled rigidity

The actual strength of metals this far remains many times less than theoretical, and here lies the reserve strength of metals.

However, for a machine or structure, it is often not durability, but stability that counts. Yet here, there is no longer much room for improvement: the properties

of the existing materials, which determine the stability of structures, are very near their theoretical maximum values. A sufficiently great load can bend a column made of high-grade steel just as easily as one made of carbon steel. In this case, the most essential factor is the form, not the material. In other words, parts subjected to compression must be sufficiently thick. However, to reduce their weight, such parts are made of several layers: the outer layer is made of the basic material and is stuffed with a less durable, light filler. This method of making parts is especially effective when the stresses in a part are distributed unevenly. Consider a wing of a modern aircraft, for example. It is the skin of the wing that bears the whole of the load. It has been suggested, therefore, that the inner cavity of a wing be filled with some substance, like metal foam, i.e., an artificially foamed alloy. Due to a multitude of air-filled cavities, metal foam is extremely light; yet aircraft engineers continued to search something still lighter. The result was a honeycomb structure.

It is extremely difficult to build a honeycomb structure (keeping in mind that it cannot be welded), but it is even more difficult to shape it to the form of a wing. Engineers were unable to solve this problem; their only solution, to avoid bending the cells during milling, was to freeze the honeycomb panel in water and then machine it to the required shape.

Stiffening ribs, honeycomb structures, metal foam... It seemed that every kind of construction had been tried. Every conceivable construction, except ... the simplest one. Why not fill a wing with hollow balls? According to calculations and experiments of A. Kovrigin, E. Stebakov and other inventors (USSR Inventor's Certificate No. 134,988), thin-walled balls are ideal structural elements with regard to lightness, rigidity and heat-resistance.

Now let us see how an aircraft wing is made today. Portions of the wing skin are placed in a special mould. The mould is filled with hollow balls coated with a high-melting solder. When heated, the solder melts, and the balls are soldered to one another and to the wing covering, thus making the wing monolithic. Apart from simplifying the technological process, engineers have for the first time been able to effectively adjust the weight and rigidity of the structure in any place: the thickness of the walls of balls is selected to suit the wing loads. The specific weight of a "ball filler" and its heat conduction are extremely low, for it is only at one point that a ball touches a ball. The latter fact is especially important whenever increased thermal insulation is required against high temperatures and intense heat flows. Because of its low heat conducting properties, a wall with a ball filler can be used as an effective insulator against cold or heat.

FRICTION WITHOUT WEAR

The wearlessness effect discovered by Moscow scientists, Prof. D. Garkunov and Prof. I. Kragelsky, has made it possible to manufacture machines that need no periodic maintenance

In 1966, the Committee for Inventions and Discoveries under the Council of Ministers of the USSR granted two Moscow scientists, Prof. D. Garkunov and Prof. I. Kragelsky, Diploma No. 41 for the discovery of "a selective transfer effect in friction". In fact, the ceremony was of a purely juridical nature, for the discovery had been made long before.

Some fifteen years ago, a group of aircraft designers sent a huge bronze ring, an axle bearing of an aircraft undercarriage, to be tested at Prof. Garkunov's laboratory. After a month of service, bearing would fail to

work despite meticulous maintenance and oiling. Widening of the clearance and other measures were of no avail, so it was decided to make the tricky friction members of other materials. As before, the leg of the undercarriage was made of steel, but now a different variety of bronze was used for the axle bearing. The result was absolutely inexplicable: the friction members showed not a trace of wear. A discovery of great consequence seemed to be made by chance. The engineers themselves cannot deny this fact and point out it would have taken many years to make that discovery but a designer's error in selecting the material for the axle bearing.

In all probability, such things had happened before, but who realized their value. Louis Pasteur used to say, "Chance only presents itself to prepared minds". This was precisely the case with D. Garkunov and I. Kragelsky, prominent scientists who spent many years working on problems of friction and wear. Having encountered an inexplicable phenomenon that appeared to contradict all conventional theories, they began to study it. Small bars of steel and bronze were put in a wear-testing machine. A bronze bar pressed with a force of 120 kg/cm^2 against a metal plate immersed in an alcohol-glycerine lubricant was kept rubbing its surface at a rate of 100 strokes per minute. No trace of wear was detected, not even by a high-precision analytical balance on which the bar and plate were weighed after testing.

It was noted, however, that the surfaces of the bar and plate were coated with a reddish, copper-like film, smooth as a mirror and no more than one micron thick. It was found out that friction continuously transferred atoms from one surface to the other. In short, it was a typical case of intermolecular interaction between two surfaces, known as cohesion. As

a rule, cohesion sharply increases wear, as it tears off metal particles and transfers them from one surface to another. The surfaces become rough, the coefficient of friction sharply increases, and the result is either wedging or breaking of friction members. In this case, however, things have reversed, something very much akin to cohesion completely rules out wear. The difference between the two phenomena is that in our case not metal particles, but individual atoms are transferred from surface to surface and circulate between them. The Moscow scientists call this process the "atom transfer".

For the first time in the history of technology, this "atom transfer" has drawn a boundary line between the two "inseparable companions", friction and wear, regarded by engineers as almost synonymous notions. In a nutshell, we have sliding without friction or wear.

This reminds one of living organisms whose joints are, in fact, ball hinges and sliding bearings which are virtually not only wearproof, but also capable of self-healing, taking care of minor scratches and the like. Of course, the similarity is only superficial, because regeneration of living organisms is infinitely more complex than the atom transfer, yet the result in both cases is the same: friction members are "wearproof". Here we have to resort to inverted commas, because friction is not the only factor that produces wear. Actually, wear is also due to abrasion, humidity which causes the corrosion of steel parts, as well as to shocks and misalignments which destroy the accuracy of joints and couplings. It is not by chance, that these factors are referred to as "secondary", as they all can be well taken care of by designers. However, no designer can eliminate friction, the rubbing of metal surfaces against one another and the transfer of loads, which is actually the basic function of bearings and joints.

Let us now assume that we have coped with the harmful effects of the foregoing factors by placing hinges and bearings in hermetically sealed and watertight packings. Let us also assume that we can somehow avoid shocks and misalignment. Shall we then obtain a wearproof assembly? Unfortunately, not always, or, to be more exact, not yet, because the scope of the invention is continually expanding as the work of the authors progresses.

As we have said, the wearlessness effect was observed for the first time for a particular case of bronze and steel friction members placed in a mixture of alcohol and glycerine. Here the lack of wear was due to the presence of copper which precipitated from the bronze and formed a fine film over the rubbing surfaces; the glycerine serving as a reducing medium which avoided oxidation of the copper; and also due to the moderate sliding speed which completely eliminated the surface effects discovered by Academician P. Rebinder, etc.

But, apparently, glycerine is no universal lubricant. Is it possible to find an effective substitute for it? A lot of experiments have been performed, perhaps, as many as there had been made by T.A. Edison, when he looked for a suitable material for his electric bulb filament. Many a substance have been tested, including beef-tea. Finally, the required properties were discovered in consistent lubricant greases containing surface-active agents with reducing properties.

But here another problem arises. Not all friction members are made of bronze and steel. How about other materials which do not contain copper? What about, say, steel rubbing against steel or steel rubbing against cast iron? There is a simple way to attain wearlessness in such cases, too. A recess is made in one of the friction members and filled with bronze. When

operating, copper comes out from the bronze and coats the mating surfaces thus eliminating wear. True, the protective layer is also somewhat subject to wear, but it restores itself at the expense of the bronze filler. This technique has been successfully employed in heavily loaded undercarriage assemblies of some types of aircraft. The wear-resistance of these assemblies has been effectively raised many times. In addition, the above method has also made it possible for the loads on steel-steel friction pairs to be increased three to four times without causing scores.

There is another patented method, referred to as friction brass-plating, which consists in applying a protective brass coat directly on the rubbing surfaces. A number of commonly used parts which are bodies of revolution, such as bolts, axles, pistons, cylinders, etc., can be brass-plated with the aid of simple equipment on an ordinary lathe.

First of all, parts have to be degreased or at least washed with gasoline. Then, the oxide film is removed from their surface with emery-cloth. Since brass-plating, too, is based upon atom transfer, one has to create favourable conditions for that process. For this the detail is coated with a thin layer of glycerine. It remains only to secure the detail between centres, start the lathe and press against the detail a spring-loaded brass rod held in the tool holder. Glycerine is nonpolar and thus does not prevent direct contact between the rod and the detail. At the same time, it is chemically active and effectively reduces the brass oxide film wherever the rod contacts the steel surface. Without glycerine, during dry friction, the surfaces of the metal are rapidly oxidized. Because of this the brass layer is rough and scaly, and the small flattened specks of brass are poorly bound to one another and easily scale off the surface of the steel part.

Tests have shown that brass-plating not only ensures wearlessness, but also makes it possible to raise loads almost five-fold, without danger of seizing, it also reduces the coefficient of friction 2 to 4 times and speeds up by several times the running-in of parts. Brass-plating is especially advantageous for low-speed joints and also when there is a need to prevent cohesion of seating surfaces of parts which are tightly fitted and which have to be periodically reassembled. Steel surfaces may be also plated with pure copper or bronze. A plating as smooth as a mirror is unsurpassed for precision pairs.

Finally, there is a third method of avoiding wear. It consists in introducing copper, bronze or brass powder into a lubricant. As a matter of fact, such attempts have been made before. For example, copper or lead powder was added to ordinary mineral oil. This not only reduced friction, but also partially restored worn-out surfaces. In one instance, the circular guides of a boring mill had been so worn out over 20 years of operation that threading was impossible. A mixture of copper and lead powder was added to the cooling emulsion and lubricating oil. The result was reasonably good threading, and the worn-out guides again became as smooth as a mirror all by themselves. This story, however, has nothing to do with atom transfer: in this case, the powders' action was purely mechanical; it did not plate the surface, but only filled up cracks and scores.

Atom transfer only takes place if a lubricant contains 5 per cent of copper, bronze or brass powders (large quantities of these are put out by the metallurgical industry to manufacture electric brushes and other ceramic-metal items), or the sort of bronze powder which is used for making paint. As soon as they are in the contact zone, particles of the powder begin to interact with the lubricant. The process is enhanced by

higher temperatures and specific pressures. As a result, steel friction surfaces are coated with a fine layer of copper, which eliminates wear and reduces friction several times.

Inventors V. Bely and B. Kupchinov of the Soviet Republic of Byelorussia used powders to reduce wear of details made of polymers. They added 40 per cent of cuprous oxide to the fluoroplastic coating which is applied to the friction surface of a sliding bearing. In some instances, wear was reduced 300 (!) times.

As regards the combined sliding speed of friction members at which wearlessness can be attained, it is still limited to 6 m/s. This is due to complex physico-chemical phenomena which the volume of this book does not permit us to deal with. Still it has to be borne in mind that there is a host of different assemblies working at such low speeds which must have a longer service life.

A few words about temperature. Prof. I. Kragelsky is very cautious when touching upon this subject. He warns that so far, scientists can only ensure self-restoration of friction members at temperatures not higher than +80°C. Exceeding this limit leads to wear. So the existing method is no panacea. Much work still remains to be done to effect atom transfer at high temperatures, but Prof. Kragelsky feels confident that in 10 or 15 years there will be self-restoring assemblies in all machines.

Speaking of wearlessness, no mention has yet been made of fluid friction. In fact, if friction members are separated by a layer of a lubricant, wear is eliminated. However, when starting or stopping a machine, before the shaft is supported by an oil film or before the oil pump develops the required pressure, temporary semi-dry or even dry friction is unavoidable. Only atom transfer can prolong the service life of such assemblies.

UNCROWNING THE INVOLUTE

For 200 years, gear teeth were shaped along an involute until Soviet scientist M. Novikov replaced it by circular arcs

One night in May 1955, Colonel Novikov, Head of a chair at the Zhukovsky Military Engineering Air Academy, was giving a party. He showed his guests something that would have seemed utterly incongruous under the circumstances unless it was the actual reason for the celebration. On the festive table was a pair of strangely shaped aluminum gears which smelt not of engine oil but of pinewood.

This was a gear drive of a fundamentally new type invented by the host. The two gear wheels had just been made on an ordinary milling machine and were still smelling of turpentine with which aluminum blanks had been lubricated during machining.

Apparently, not a single more or less complicated mechanism can do without gear drives. Take a car, for example. To start the engine and get the car going, you press the starter. From the starter, rotation is transmitted to the crankshaft by gears. The rear-axle drive of a car connecting the cardan shaft to the rear wheels also contains gears, as well as the differential which makes it possible for the rear wheels to rotate independently of each other. The oil pump which forces lubricant to bearings and other friction members of the engine also has gears. In fact, the oil pump is nothing but a pair of gears conveying lubricating oil in the spaces between their teeth. You turn the steering wheel, and its rotation is transmitted to the wheels of the car by gears; the windshield wiper, too, operates through gears. As to the gear-box, every schoolboy knows that it is a box with a multitude of gears. There are gears

in the car doorlocks, they are also mounted on the control rod which opens and shuts the valves of the cylinders. In short, there can be no car without gears.

A clock is a still better example, for with the exception of the spring and the pendulum, it contains nothing but gears.

At first sight, a gear drive is very simple. One tooth engages another and thus transmits rotation. The more teeth, the slower the rotation of the gear with respect to the one that drives it and vice versa. But in fact, the theory of gear drives is extremely involved. Thousands of laboratories and design bureaus have been working for more than 200 years on the structural design of gears, their accuracy, wear-resistance and the methods of their toothing, grinding, hardening, oiling and cooling.

Take a closer look at a gear: every tooth has a certain curvilinear shape. This shape determines the uniformity of the gear rotation and, in fact, the possibility of gearing. It is notable that every gear wheel is shaped as an involute, which is a mathematical curve easily drawn by winding a thread around a disc, tieing its end to a pencil and unwinding the thread, pressing the point of the pencil onto a sheet of paper.

The involute shape of gear wheels was first suggested in 1754 by Leonard Euler, the outstanding mathematician and member of the Academy of Sciences of St. Petersburg. It had a number of important advantages and reigned supreme in machine-building for 200 years until it was faced by a formidable rival, the new type of gear drive invented by M. Novikov.

Mikhail Novikov was born in 1915, two years before the Socialist Revolution swept Russia. He started his career as a metal worker when still in his teens, and after several years became a student in the Bauman Technological Institute of Moscow. In the thirties, the

Komsomol, the largest Soviet youth organization, called on young men to enter aviation, and M. Novikov responded to the call. In 1940, he graduated from the Air Force Academy and stayed to lecture there. In 1955, he brilliantly defended his Doctor's thesis, the work of his lifetime. The subject of the thesis was the new type of gear drive. M. Novikov died three months before the opening of the First National Scientific Conference devoted to his invention. The Conference named the new type of gear drive after the inventor. In 1959, Dr. Novikov was posthumously awarded the Lenin Prize, the highest Soviet award for outstanding achievements in science, technology and arts.

Involute-shaped teeth are reasonably good, but are not ideal. They require a high dimensional accuracy and have to be made of an extremely hard material. Their worst disadvantage is the development of high frictional force thus generating heat and causing the teeth to wear quickly. Gear drives of this type are heavy and cumbersome. Suffice it to say that more often than not, an automobile reduction gear which transmits rotation to the wheels is twice as heavy as the engine. Because of this it is necessary to have a substantial amount of oil and install a special oil cooler.

Dr. Novikov suggested that involutes be replaced by circular arcs or smooth curves which are similar to them. The teeth of one gear are convex, while those of another gear are concave. This improves the mating (meshing) of the two gears; the contact area is increased, and the unit pressure over this area decreases. Hence, the advantages of the new type of gear drive: friction is more than twice as low; wear, 3 to 6 times less; and the weight has been halved. High dimensional accuracy is no longer so important: during operation the friction members run in themselves. Extreme hardness is not a requirement, so gears may now

be made of aluminum, unhardened steel or plastics. Grinding and hardening, too, are not necessary.

All this, of course, effects a great saving of labour and material, but it would have been difficult for Dr. Novikov's gears to win the race unless they had been able to meet an important requirement, i.e., simplicity of production. Usually highly complicated and expensive machine-tools are needed to cut the conventional gears. There are scores of thousands of such machine-tools all over the country. Are all these to be thrown away? No, because Dr. Novikov's gears can be effectively made on conventional machine-tools, it is only the cutting tool that needs changing. As the tooth depth of Dr. Novikov's gears is almost half of conventional gears, they can be also made easily on special rolling mills.

At first, Dr. Novikov's invention aroused much scepticism. Experts refused to believe that such a gear drive could rotate, but its effectiveness was demonstrated in practice. Time has corroborated the correctness of Dr. Novikov's calculations. Engineers have now devised a gear drive which develops, even with roughly machined teeth, a peripheral speed of almost 100 m/s and transmits a colossal power of nearly 15,000 hp.

Every invention has a specific sphere of application where it can be used with the greatest advantage. As regards Dr. Novikov's gear drive, this sphere is practically unlimited.

2. Meaningful Noises: Flaw Detection and Control

Reliability is a basic requirement of any instrument, plant or machine. The most ingenious machine is nothing but useless unless it is reliable. Sufficient reliability and long service life of highly complicated automatic complexes, spaceships and assembly lines can only be ensured by the high quality of their components, their accurate assembly and continuous checking while in operation, as well as by detecting faults as soon as they appear. This means that instruments are necessary for checking metal billets; all kinds of test installations and multiple switching control devices by which temperature, pressure and density in any part of a system may be inspected a number of times over a period of only one second. We need sophisticated diagnostic systems and many different types of flaw detectors and sensors, for, to quote Academician V. Trapeznikov, "Reliability is the key which opens the way to large-scale automation".

FOUCAULT CURRENTS IN THE ROLE OF SHERLOCK HOLMES

Electromagnetic flaw detectors give 100 per cent control

All manufactured articles, whether they be gear wheels, ball bearings, electric motors or automobiles,

must be thoroughly checked, otherwise it is impossible to ensure the required reliability of machines and instruments. However, as many checking operations are labour-consuming, it is often absolutely impossible to perform them in their entirety with the existing technical means. Hence, a number of defective products, despite the fact that at some factories quality inspectors constitute one-fourth of all the employees, is unwittingly accepted.

The reason is that until recently sufficiently effective and versatile instruments capable of ensuring a complete quality check of metal, blanks and parts have been lacking. At first sight, the problem seems insoluble. Indeed, is it possible to produce an instrument, a jack-of-all-trades, that sees everything and overlooks nothing, neither the minutest scratch or cavity, nor the smallest deviation from the preset metallic structure? Indeed, is it possible to find an instrument that can detect deficiencies of thermal processes, measure residual stresses after grinding and welding which reduce the fatigue strength, record residual magnetization impermissible for bearings of precision instruments and, finally, detect dimensional errors?

Despite the complexity of the task, a universal instrument capable of replacing hundreds of single-purpose ones has been produced.

* * *

Jean Bernard Leon Foucault, physicist at the Paris Observatory, was the first to pay attention to electrical eddies which subsequently were given his name. These eddies are observed in a metal each time when a change occurs in the surrounding magnetic field. Due to this, cores of electric machines are made of thin steel plates

separated one from the other by insulation, otherwise much energy is wasted for unnecessary heating of magnetic circuits. The Soviet inventor Tadeusz Gorazdovsky, Cand. Sc. (Tech.) decided to use these seemingly harmful currents.

In practice it was difficult to implement his invention, although the principal idea underlying it is so simple that it can be easily described in a few words.

A power current (of 50 Hz) is supplied to magnetizing coils which produce a varying magnetic field. The part to be tested is placed in that field. Foucault currents are induced in it, each producing a magnetic field of its own. Owing to the magnetic fields produced by these currents, an electromotive force is induced in the induction coils of the instrument. It is amplified and transmitted to the screen of a cathode-ray tube. The quality of the tested metal is assumed from the amplitude, phase and frequency of the observed voltage.

The inventor has named his instrument "emid", which is the Russian abbreviation for the electromagnetic inductive flaw detector.

* * *

What is the basic difference between the emid and other types of flaw detectors? First of all, it is based on the analysis of eddy currents and immediately gives a number of characteristics, namely, nine. This is due to the resolution of the obtained curve into three fundamental harmonics, each having a specific amplitude, phase and frequency. Just as nine unknown quantities can be determined from nine algebraic equations, the nine parameters in our case unambiguously determine

nine values which characterize the quality and properties of a metal.

What do we mean by saying "unambiguously"? Just imagine that the magnetic and electric properties of a specimen have somehow changed. Why does it happen? Is it due to a change in the chemical composition of the metal or a change in its structure? It is impossible to find the answer with the aid of an ordinary pointer indicator which measures only one parameter, just as you cannot picture the shape of a part from only one projection. It is quite easy, though, if you have two or three; in our case we have nine projections, i.e., nine parameters.

What is still more important, the emid enables us to determine not nine but a greater number of characteristics. It is certain that a number of metal properties, such as ultimate resistance and yield limit, elasticity modulus and impact strength are related, although these relationships still require further study.

* * *

Every instrument is supposed to ensure a certain accuracy of measurement. In this respect, the emid has no match.

For example, it easily distinguishes between steels having almost equal chemical composition. It determines carbon content to an accuracy of 0.02 per cent, whereas the permissible deviations may be one and a half times higher. Incidentally, carbon content cannot be determined by special analysis, as the analyzer electrodes themselves are made of carbon.

It is well known that the sharper a crack in a part, the more dangerous it is. It is precisely for these cracks that the emid has the keenest "eye", as they are better seen on the screen.

Conventional durometers measure hardness to an accuracy of plus or minus one Rockwell unit, the emid, however, does so to an accuracy of one tenth of a Rockwell unit.

Emids can detect internal stresses, measure dimensions and depth of carburizing, nitriding and decarbonization.

In a word, emids can measure almost any parameter if the material is a good conductor of electricity and if a flaw is no deeper than 5 to 8 mm from the surface.

* * *

A large-scale introduction of emids into the metal processing industry promises almost unbelievable profits in a vast number of fields.

To begin with, imperfect technological processes in metallurgy result in a great percentage of defective rolled stock. On the average it reaches 30 per cent, while in some cases it may exceed 90 per cent. This means that 30 per cent of the production capacity of machine-building factories is wasted because of faulty blanks. Electricity is wasted eight hours a day, and lathes and drilling machines produce faulty parts that will be scrapped anyway. Just think how much time and energy could be saved if faulty blanks were detected as they leave the rolling mill. Emids are just right for this work.

Furthermore, the risk of hidden internal defects necessitates a manifold increase in the safety factor. In addition, to achieve the highest quality some vital members have to be selected out of a thousand. Emids can automatically do this.

Emids raise the productivity of a quality inspector thousands of times. For example, it takes 4 to 5 hours

to measure the carburized depth of gears by conventional methods, to say nothing of the fact that one batch of these costly parts has to be destroyed for the purpose. It takes an emid only 2 to 5 seconds to do the job, without resorting to destruction.

This equally applies to bearings. To determine the hardness of a ball, it has to be "punctured"; doubtless, such a ball can no longer be used. On the contrary, emids are capable of performing effective non-destructive checking of balls.

At any machine-building factory, mass production is checked at a mechanical testing laboratory. Tensile-testing machines are often installed in the production line. All this bulky equipment may be advantageously replaced by emids.

One more point. Automation is unthinkable without all-round effective non-destructive checking. At present, the production process ends up with checking operations. As a rule, checking is done manually. Before a quality inspector detects faulty production and gives a signal to stop the work, the automatic line turns out piles of defective items. Even if this does not take place, idle time is unavoidable, anyway. The best way out is continuous non-destructive flaw detection. For this, emids are absolutely irreplaceable, for they effectively detect the minutest and most diverse faults: cracks, backfins, crazes, blisters, disproportions in the chemical composition and flaws due to faulty heat treatment, etc. The movement of parts being continuous. Along the assembly line, parts pass through sensing coils. That is all there is to it. Built into automatic lines at metallurgical and machine-building plants, emids can instantaneously detect faulty production and immediately adjust the "erring" assembly.

PIGEONS AS ASSEMBLY LINE INSPECTORS

Specially trained pigeons replace quality inspectors in automatic lines at bearing, watch, button and pharmaceutical factories and confectioneries, i.e., in all places where thorough visual checking of mass-produced articles is vital

It is well known, the growth of man's knowledge helps not only to increase the number of useful things, but also develops profitably those already existing. The development of science supports this assertion again and again.

For example, uranium was discovered as far back as 1789, but for a long time its application was confined to glass manufacture. It fully owes its importance in recent years to the development of nuclear physics. Silicon is another example. It is now known as a wonderful semiconductor, but this, too, is a very recent discovery. Metallurgical slags used to be regarded as waste; at present, they serve as an important raw material for the building industry. One could think of other examples of this kind.

There are similar developments in zoology which has become an inexhaustible source of fresh ideas for bionics. Studies of the skin and the shape of whales' and dolphins' bodies help designing of high-speed vessels; studies of water fleas enable designers to evolve orientation systems for spaceships; sensitive pickups connected to ganglia, i.e., nerve centres of an ordinary fly, warn miners of a leakage of dangerous gases, and astronauts, of a leakage of fuel from rocket pipelines.

Animals themselves have mastered a number of new "professions" with the aid of engineers and zoologists. In the German Federal Republic, for instance, specially trained dogs locate faults in underground gas

lines. Suppose a pipeline has rusted through. How do we detect the leak if the line is deep in the ground and stretches over hundreds of miles? The specially trained dogs are highly-sensitive to the smell of different gases and never fail to bring a repair team to the right place, even if the air is full of other odorous substances: smoke, blow-outs from chemical and metallurgical plants, etc.

Another example. Forestry requires large amounts of seeds. Therefore, gathering seeds is a vital problem. In Canada, for instance, this is done with special mobile lifting machines strongly reminiscent of those used by electricians while repairing tram and trolley-bus wires. In the forest, however, the manoeuvrability of such machines is limited, so in most cases seeds are gathered by hand. Equipped with hooks and safety belts, gatherers climb trees all day long, picking nuts and cones.

Recently, one reputable scientific journal suggested using squirrels to do the job. It is only necessary to provide squirrels with proper "storehouses", i.e., plank or wattle and daub boxes mounted on trees, and then from time to time the seeds can be callected from their stores.

Just like human beings, some animals master new professions, while others, like pigeons, sometimes have to give up the old ones. This is the case with carrier pigeons which have been serving man since the days of ancient Egypt. On their way home from Crete, Egyptian seafarers sent winged messengers to herald their arrival. The forces of Julis Caesar and Marcus Antonius also used carrier pigeons. Thanks to pigeons, Natan Rothchild, the London banker, learnt about Napoleon's defeat at Waterloo three days before the news reached the British government; he had ample time to corner all the appropriate shares, and thus greatly augmented his fortune. With the advent of photography pigeons

were used to carry light cameras for aerial photography. In 1871, during the siege of Paris, pigeons were transported from the city in air balloons. Upon their return, they brought much valuable information. In 1929, carrier pigeons brought a message from the "Graf Zeppelin" flying over the Pacific.

In Russia, pigeon-breeding is a long-standing tradition. More than 100 years ago, in 1856, a special Committee on pigeon-breeding was set up on the initiative of A. Bogdanov, Professor of Moscow University. In 1891, plans were worked out for a pigeon service between Moscow and St. Petersburg with an intermediary station at Bologoye. Today, pigeon-breeding is a hobby of the past. Radio, telegraph and aviation have rendered pigeon post hopelessly obsolete, it is now only a pastime of inveterate pigeon-fanciers for whom their hobby will always remain precious, no matter what new wonders atomic engineering and cybernetics may yet perform.

A. Bykov, assistant chief technologist at a machine-building factory in Moscow and an old pigeon lover, one day came across an article about pigeons. It said that these birds have exceptionally good visual memory and can instantaneously discern the outline, shape and colour of different objects. This helps them to find their bearings on the ground. A. Bykov thought that there might be another way of using these remarkable abilities.

He confided his idea to a couple of co-workers, also old pigeon lovers. They were S. Lapshina, a designer, and A. Panteleyev, Head of a laboratory. The trio immediately set to work, keeping it a dead secret so as not to set sceptical tongues wagging.

To start with, some pigeons were to be bought, so they went to Konny market. Incidentally, A. Chekhov, the famous Russian writer, often came here. It was Sun-

A pigeon sorting out products on a conveyor

day, and the choice was large. There were tumblers that could plumb dive and do all kinds of stunts in the air; shags with feathery tufts on their legs which looked like another pair of wings: “chistiye”, or pure doves, the local Moscow breed unsurpassed in winter conditions; “tucherezy”, or cloud-cutters; fan-tails; jacobins with feathery jabots around their necks; trumpeters, and a host of other species.

The three engineers bought the cheapest pigeons making sure they were no gourmands and would be

content with such plain food as hemp seeds. A. Bykov deliberately starved his pigeons for two or three days until they became tame and ate from his hands. However, the most complicated part of the experiment still lay ahead.

As you surely have guessed, the three Moscow engineers made up their minds to use pigeons for visual control, to make them sort manufactured-articles, picking out defective ones. At present, scores of thousands of people are engaged in this tedious mechanical work in many branches of industry. Their eyes, reddened with fatigue, follow the incessant flow of millions of buttons, buckles, pills, washers, nuts, bearing balls, vaseline boxes, and so on. With the annual increase in the volume and quality of production, the demands for visual control are ever increasing. Even today, it often takes as much time as manufacturing itself. Of course, there is nothing basically wrong if somebody fails to detect a scratched button; but a black point on a ball bearing may cause fatigue and eventually an accident; a tiny burr of metal from a washer corking up the hydraulic system of an aeroplane or rocket may be fatal. It is natural for man to overlook such trifles: his eyes are soon become tired when following the passage of absolutely identical objects and he gets drowsy.

To train their pigeons, the three engineers made a special bench at A. Bykov's apartment. The bench was very simple in design. Just a wooden box whose bottom was made of clouded glass which served as a screen. A pigeon was placed in the box. Attached to the glass on its right and left were two rectangular plates provided with contacts. Underneath the pigeon was a transparent disc through which it could see well illuminated articles that were fed from a special bin and placed, one after another, in the checking position. If the article is good, the pigeon pecks at the plate on the right; with

a faulty item, the one at its left. Contacts are then closed and a mechanical arm removes the defective item. The pigeon at once receives its prize: a seed from a contact-operated feed bunk. Very simple, rational and ingenious. Yet, it was hard to make it that simple. Pigeons are very shy, to train them properly was as difficult as adjusting some complicated electronic device. Some pigeons were irritated by the light, while others refused to feed from the bunk. Some pigeons pecked at the plates with a greater force than others, so it took plenty of time to select proper springs for the contacts. Several times the trio grew desperate and were about to give up the whole thing, but after a few days they cooled down and resumed their work. At last it seemed that things were improving; the pigeons learned to sort out bearing balls. The inventors were happy, but the very next day the winged quality inspectors started rejecting all balls, good and bad. The engineers doubled the prize, improved the lighting, to no avail. The inventors almost lost hope when suddenly the reason was found, and a very simple one. The fact was, the pigeons noticed fingerprints on the smooth surface of the balls and rejected them as defective. Once the balls were wiped with a piece of cloth, everything went like clockwork.

Summer came. Our pigeon lovers went on vacation for a month. When they came back it seemed they would have to start from scratch. Svet and Bion, the happily billing and cooing newly-weds, were hatching their eggs, oblivious of everything but their "traditional" duty.

This did not worry the inventors, though the major difficulties had already been overcome: the bench had been designed and made, and the training methods evolved. New pigeons in a few days were as good as the old ones. Again they began with bearing balls, but

soon the pigeons learned to sort buttons, washers, nuts and cotter pins, without missing one single item with a dent, barb or hair crack. They were also good at sorting sweets and vaseline boxes, detecting even the minutest changes in the decorative pattern of the wrapping. They could check very small items, too, displayed under a magnifying glass. It is interesting that being given a prize only for detecting a faulty item, a pigeon never cheated to get an extra seed. Apparently its "honesty" is accounted for by a stable conditioned reflex.

Preliminary training of a pigeon takes from 3 to 5 days, depending upon its capabilities. In two or three weeks, its skill substantially improves; its sight is keener than man's, so it can see defects which go unnoticed by a naked human eye, the smaller they are, the more attentive a pigeon becomes. A pigeon can check from 3000 to 4000 items per hour and can work this way for several hours continuously without showing any sign of fatigue and without reducing the quality of its work.

In the course of my interview with A. Bykov I asked him what would happen if a pigeon fell asleep or stopped pecking at the contact plates.

A beautiful white dove perched on his shoulder lowered its head as if it understood what we were talking about.

"An interlocking device will stop the supply of items for inspection", he replied.

"But suppose there are so many defective articles that the pigeon overeats?" I asked.

A. Bykov laughed the matter off. "In that case we shall have to fire those responsible for the shoddy work", he said. "Believe me", he went on, "we have spent so much time and effort to complete our experiments. We have thought of everything. In the near future we are

going to use pigeons for quality inspection at a small button factory, at present seven women do this work. After that we are going to tackle vaseline and shoe polish boxes, toys, china-ware, kitchen utensils and porcelain statuettes. It would be just grand if rationalizers all over the country joined in this venture. Pigeons could doubtless be used at canneries and at fruit and vegetable storehouses. As regards large-scale employment of pigeons in radioelectronics, instrument making and other industries that produce highly important parts, we have to overcome a psychological barrier, as some people argue that nobody can be responsible if a pigeon makes an error. This point of view is obviously groundless. I am absolutely confident that pigeons are better quality inspectors than human beings. They neither get tired so quickly, nor mind monotonous work. The cost of keeping them is negligible. Several pigeons placed at different sections of a conveyor can after training sort out different types of defects; they can separate repairable articles from those to be scrapped. I am sure new possibilities will occur which we cannot think of right now".

"Well, we assume from our talks that pigeons are more reliable than human beings", I said. "But there are machines for sorting bearing balls. These must be absolutely reliable".

"This is where you are wrong", A. Bykov retorted. "I know these machines. They are used at a number of ball bearing plants and incorporate photocells that measure the brightness of a light beam reflected from the surface of a ball.

These machines cannot detect hair cracks which may be very dangerous, but pigeons can. Are bearing balls the most difficult parts in the world to inspect? No, in fact, they are the easiest. It is infinitely more difficult to make a machine detect barbs or scratches. We do not

have any such machines yet and it'll take quite some time to design them. For such work, they must be able to recognize images, a major problem facing cybernetic engineers. These machines will have to be provided with high-quality optical equipment having high resolution, with special programming of each individual article. A pigeon, however, can be easily transferred from one job to another. Two or three hours are sufficient to re-train it. Pigeons are cheap to keep, do not need any special care and are absolutely reliable. In view of all this, they are unlikely to encounter any competition in the next few years. Any plant or factory can have a pigeon-house of its own and use pigeons for visual inspection of parts thus saving the wages of quality inspectors."

THE SMELL OF DRILL: A SIGN NOT TO BE OVERLOOKED

The use of odours opens up ways for raising the reliability of machines and automatic lines

Along the reinforced concrete columns of a machine shop there are long rows of automatic machines. Rams move rhythmically up and down, milling cutters revolve at breath-taking speeds, gushing out a shower of golden sparks, and abrasive discs are sonorously ringing. There is not a soul here, only a beautiful Alsatian dog laying on a mat by a window, basking in the warm summer sun.

Suddenly the dog is alerted. It rises from the mat, sniffs at the air and rushes, with a loud bark, to an operating lathe. In a couple of minutes a repair team arrives. The men look worried. "Yes, the guides have worn out", they say and stop the lathe.

It has to be admitted that this method of control-

ling machine-tools, presses and lifting equipment has not yet been introduced into production, but it may be used successfully if the invention made by A. Poshenko, a Tashkent engineer employed at the Central Asian Scientific and Research Institute of Geological and Mineral Raw Materials, is utilized.

While drilling test wells, he was often faced with a specific problem well-known to any drill operator. Drilling proceeds smoothly only if the drill bit or some other rock-boring tool is not worn above a permissible limit. But how do we know when this limit is exceeded? This cannot be calculated in advance, because the axial load upon the tool, the number of revolutions and the rock hardness are continuously changing. Nor is it possible to actually see the tool which is hundreds of metres underground. The drill operator has to rely upon his experience. Whenever he sees that the downward movement of the drill is too slow he gives order for the drill to be brought to the surface. It often turns out that the bit of the drill is in good condition and it was simply a stone causing the slowdown. Such unnecessary hoistings take much time, reduce the drilling rate and often reduce operators' wages. How do we effect a reliable tool inspection without resorting to complicated electronic devices and pickups? Incidentally, there is no room for these devices in a narrow well.

A. Poshenko hardly remembers what prompted the idea of using smells to solve the problem. Perhaps, it was due to his and his colleagues' current interest in chemistry and the desire to use chemical methods in their work. As regards the engineering problem, its solution was quite simple: the inventor suggested that tiny cylindrical aluminum capsules containing a strong smelling substance be pressed into small holes between the teeth of a drill bit which was then used in

the usual way. When the wear limit is reached, the capsules are worn through, and the air coming out from the well is contaminated with the odour of the substance. Very simple, inexpensive and reliable: the capsules need no special room, maintenance, adjustment; moreover they are not affected by vibration, humidity or temperature fluctuations. It only remained to find a suitable substance with a strong characteristic smell. A. Poshenko spent days studying reference books on chemistry, consulted scientists. Finally he selected ethyl mercaptan: a cheap, easily available substance commonly used to odorize natural gas. Tests were a success. The inventor was granted Inventor's Certificate No. 163,559. There can hardly be a simpler and more feasible and effective method. Economic gains are also great; drilling with air blowing is by 20 per cent cheaper than conventional drilling. The volume of such drilling in the USSR amounts to 3 million metres a year.

With all its practical value, A. Poshenko's invention is but one of the first tentative ventures into the realm of odours which has wide practical prospects in many fields of engineering and technology. In terms of cybernetics, the prospects opened up by this invention stem from the tremendous discrimination power of the sense of smell possessed by living organisms. Experiments carried out by R. Gasteland of Great Britain have shown that while frogs are capable of distinguishing some 250 different smells, the corresponding figure for rabbits goes up to several million. This equally applies to man.

By smell man can immediately distinguish complex chemical substances the analysis of which would require months of hard laboratory work by an experienced chemist. Another important point in this connection is that man can sense negligible concentrations of odorous

substances that cannot be detected by any instrument. A great number of animals and species of fish has an infiinitely more acute sense of smell. This accounts for the fact that dogs can follow a scent and explains why fish have no difficulty in finding the way to their spawning grounds thousands of miles away. We do not know yet the manner in which the nose and brain distinguish smells, although for over a thousand years this problem has been of interest to many outstanding scientists, from Lucretius Carus, the Roman philosopher and poet, down to Academician A. Joffe of the Soviet Union. More than thirty different theories have been advanced to explain this phenomenon in recent years, yet none of these fully agrees with experimental data. This, however, is no obstacle for experiments trying to make practical use of odours.

Suppose we attach capsules filled with odorous substances or pads, washers and the like impregnated with such substances to those parts of machine-tools, cars, trucks, lifting equipment, etc. that are subject to wear. Since our noses immediately detect smells, we shall know at once if some part has been worn to a predetermined limit. This method can be especially useful in the case of automatic lines and machine shops where each setter or maintenance engineer has to service scores or even hundreds of machine-tools. Even the highly skilled find such work extremely tiring. The above method makes it possible to spot at once a blunt cutter, a worn-out mill, guide, etc. The smelling task may be even performed by a dog. Incidentally, in Belgian mines, canaries have long been used to warn miners whether harmful gases are present; in the German Federal Republic dogs are used to find leaks in underground gas lines; and in the United States, scientists have been looking for ways to make flies pinpoint leaks in hydraulic and fuel systems of rockets.

The simplicity and advantages of this method become particularly obvious when it is compared to the method of checking wear by means of radioactive isotopes. Just think how many pickups and recording instruments would have to be installed in a shop and how much connecting wires would be necessary to feed all readings to a central control desk which, in addition, would have to be placed in a convenient position for the controllers to observe the entire shop! Also the further complications as safety precautions, deactivation and repeated radioactive labeling of parts. The above method eliminates all these difficulties. Modern chemistry can easily provide substances which, apart from being absolutely harmless, would even have a pleasant smell. From the point of view of engineering, another important advantage is that it renders immaterial a number of otherwise important considerations. It makes no difference, if a wearing part is on the surface of a machine or deep inside it, whether it is fixed or makes thousands of revolutions per minute. In combination with the high information capacity of the sense of smell, these advantages open up fundamentally new opportunities for making highly reliable machines and automatic plants.

GAUGE FROM A RAINBOW

Instantaneous size checking. Micron accuracy by eye. A green halo shows the item is oversize, a red halo indicates it is small

It has always been considered that it is most essential to manufacture a part, but the removing of burrs and barbs is a matter of no consequence. As a result,

major technological processes have progressed faster than auxiliary ones. We produce hundreds of intricately shaped articles per minute from very accurate dies; we have automatic machines which instantaneously drill micron-wide holes by means of a laser beam or an electric spark; we have electron guns that can spray in a vacuum millions of minute semiconductor resistors, capacitors and condensers. Engineers have, however, been paying much less attention to such things as deburring or dimension checking. As a result, these processes are among the most labour-consuming operations. Nowadays, it seems perfectly natural that it is far more difficult to measure an article than to manufacture it, and the smaller the article, the greater the problem of measurement. The situation is further aggravated by miniaturization and microminiaturization of modern production. The dimensions of TV and radio sets, sophisticated electronic devices and instruments employed in aircraft and spaceships are being reduced from year to year. While their reliability and accuracy requirements are becoming increasingly stringent.

Imagine a small plate, only a few millimetres wide, having a complicated contour with scores of holes of different diameters and shapes. Parts like this are used in watches, cameras and navigation instruments. It is necessary to measure the dimensions of the holes, the distances between their axes and the entire geometrical pattern of the part to an accuracy of a few tenths of a millimetre, a kind of work which even Levsha* could not do.

* Levsha is a legendary Tula craftsman and the main character of a short story by Fyodor Leskov, the prominent 19th-century Russian author. Levsha's skill was so great that he managed to shoe a flea.

An inspector places an item to be checked on an optical measuring machine, adjusts micrometer screws and strains his eyes to read the barely distinguishable reference scales. One item is followed by another, it is like this all day, little wonder that towards the end of the day the inspector's efficiency goes down and he even unavoidably makes errors. Control operations have become the bottle-neck at thousands of industrial enterprises.

Yuri Kolomiytsev, Head of the Optical Measurements Laboratory at the Vavilov State Optical Institute in Leningrad, and Efim Finkelstein, Head of the Design Bureau at the Novosibirsk Instrument-Making Plant, found a most ingenious solution to the problem. They invented a method which makes it possible for a naked eye to measure parts which are of the most intricate shape to an accuracy of a few microns (Inventor's Certificate No. 122,612). True, this method is only suitable for flat details, but these are the ones most commonly used in instruments and electronic devices.

The method is comparative, and its most essential feature is that instead of comparing an item to a standard, a direct optical comparison is made between their projected images. This is done by using a special instrument referred to by the inventors as a "profile comparison microscope". The instrument resembles an ordinary microscope and the only difference is that it has two microscope stages and two objectives.

Let us now see how the new method is used. A reference item is placed on one microscope stage and the item to be compared, on the other. Light is switched on. Beams of light pass through the transparent stages and two differently coloured filters, so that one item appears green and the other, red. The optical systems of the objectives project both images in the focal plane of the microscope eyepiece and accurately

match them. Since red and green are complementary colours, then the correctly matched items have a colourless whitish image, but in those places where they differ, either a bright red or green fringe, depending upon which item protrudes over the other, is seen. This is an indication of a defect. Obviously, it takes much less time as it is easier by far to detect an iridescent fringe than to measure all the dimensions. If we want to know the exact value of a deviation, we resort to adjusting screws; as soon as the iridescent fringe disappears, it only remains for the scale to be read.

This microscope has another important advantage. Despite a limited field of vision, only 3 to 4 mm, which is unavoidable for significant magnification, it is possible to check sufficiently large items, provided their length is contained within the working field of the microscope stages of the instrument and because the movement of the stages is synchronized, i.e., the images remain matched with each other. Thus we can place in consecutive order all the measuring points of the detail shape in the field of vision and ascertain whether or not an iridescent fringe appears.

Some years ago, the Novosibirsk Instrument-Making Plant produced an experimental model of the instrument, but this prototype was not sufficiently suitable for production shops. Now the plant is about to start the production of a new improved model.

It is obvious that the new control method can be used with great advantage even today; in the near future, it will be used to automatize all checking processes. For this, the instrument will contain a feeding device and an actuating mechanism that will separate defective items from good ones and will be triggered by signals from a photocell which reacts only to the red or green colour.

PRESSURIZED AIRSCREW

Pressure gauge crack detection

An engine flame-out is an unpleasant event for a pilot. It is extremely difficult for a safe landing to be accomplished in such a case, especially when piloting a high-speed aircraft. A helicopter is much safer in this respect. If an engine failure occurs the large blades are set rotating by an incoming airflow (experts call this "wind milling") and the blades act as a parachute, thus ensuring a soft and safe landing.

What if a blade breaks? To avoid this, blades are regularly subjected to thorough checking with the use of the latest techniques; apart from visual inspection, these include magnetic, ultrasonic and luminescence flaw detection. The use of these methods, however, is hindered by the fact that the load bearing elements of blades, i.e., the spars, are for the most part covered by the upper skin. X-ray methods are ineffective because of the costly and bulky equipment and the films may be wrongly interpreted. Even this is not the main thing. A crack can appear directly after an inspection and cause an accident.

The Soviet inventor A. Borshchagovsky suggested a pneumatic method of continuously checking the blades (Inventor's Certificate No. 151,936). It works as follows. Air is pumped into a blade. Special pickups built in it register the air pressure and continuously pass this information to an instrument on the pilot's control panel. As soon as a hole or crack appears in the blade, no matter how small, the resulting leakage reduces the air pressure inside the blade, and the instrument warns the pilot of the coming danger.

3. Giants of Modern Machine Construction

The development of all fields of science and technology has always been marked by a characteristic expansion, by a desire to advance man's potentialities in all directions. Thus, man has obtained ultrahigh and ultralow temperatures, ultrahigh vacuum, superhigh pressures, ultrahigh-strength, super-plastic and superconducting materials and has been able to study the interaction of superhigh-energy particles. Each new "ultra", "super" or "hyper" signifies another step forward along the road of scientific and technological progress.

Man's inborn desire to master extreme parameters is also reflected in the continually growing dimensions of machines, assemblies and structures. Records are set and broken every day. Recently the Moscow skyline became dominated by the ultrahigh Ostankino television tower (a district on the outskirts of the city). This tower is the highest all over the world. Some years ago, in the United States was built the world's first structure containing a volume exceeding that of the famous Cheops pyramid, which is about 2.6 million cubic metres. According to the 1966 UNO statistics, the city

of Nagoya in Japan could boast of having the world's biggest blast furnace of 2200 cubic metres. At present, the record is held by blast furnace No. 8 of the metallurgical complex in Krivoy Rog with its volume of 2700 cubic metres. The furnace began operations on the eve of the 50th anniversary of the 1917 Socialist Revolution.

"Rockets today weigh as much as cruisers of World War I", noted B. Rauschenbach, Corresponding Member of the USSR Academy of Sciences, at the UNO-sponsored International Conference on the studies and uses of space for peaceful purposes, held in Vienna a few years ago.

The size of modern seagoing vessels would make even Leviathan, the giant, look dwarfish by comparison. The biggest vessel of today is a Japanese-built tanker with a displacement of 318,000 tons. We shall not have to wait long for vessels having a displacement of 500,000 tons; it is also significant that the ship-building company "Bureau Veritas" of Norway believes that it is feasible to build a giant with a displacement of 1,300,000 tons.

The situation is much the same in the field of classical engineering, where the Soviet Union is the leader and a holder of a great number of records. It has manufactured, for example, the world's biggest hydraulic press with a compressing force of 75,000 tons, which makes it possible to stamp parts of unheard-of sizes. Other Soviet-made mechanical giants include the EVG-35/65 excavator which is unsurpassed for its radius of action (65 metres) and discharge height (45 metres), the world's biggest boiler-turbine power plant, etc.

Gigantic machines are far from being the current vogue in engineering. Their growing dimensions are due to the objective needs of engineering and econom-

ics. Thus, each giant excavator employed at the Cheremkhovo coal basin in Siberia saves some two million roubles a year.

It is instructive to take a close look at these engineering giants. First of all, their designs are indicative of the integral link between practical engineering and fundamental theoretical research. This is because the manufacture of super-powerful machines is so costly that risks cannot be taken. On the other hand, the distinguishing features of their design are so unique that there can be no question of evolving them empirically by analogy. Besides, quantitative changes entail qualitative developments. It is not only the size that distinguishes gigantic machines from their predecessors. They are, more often than not, based on fundamentally new principles. For instance, for the output of generators to be further increased, designers had to think about ways of using superconductivity. In an effort to augment the output of power plants, power engineers spare no pains to obtain new refractory materials and study the physical properties of substances in extreme working conditions, and to further improve the efficiency of thermodynamic cycles, they are beginning to apply thermal dissociation and ionization of hot gases. Superpower presses, diamond synthesis and steel extrusion plants would have been unthinkable without the profound studies in solid-state physics and without the knowledge of the behaviour of substances subjected to superhigh pressures.

Furthermore, some giant machines pave the way for others. For example, a superpower press was needed to stamp parts for the jumbo aircraft "Antaeus". This, in turn, made the press designers think of increasing the productive capacity, to master new technological processes, including electroslag welding, and to introduce more reliable control methods, etc. This

technological chain reaction swept the entire press-making industry and accelerated its development.

Finally, the very impossibility of further increasing the dimensions of machines and of an unbridled growth of the scope of production often compels designers to seek for fundamentally new technical solutions, to change the conventional technological processes and improve in every way the existing machinery. In some instances, giants were turned into dwarfs, thus improving their efficiencies many times.

In a word, it is precisely in the field of superheavy engineering that the borderline is drawn between the machines of today and those of tomorrow.

MECHANICAL TITANS

Hydraulic presses with a compressing force of several hundred thousand tons

"It is no exaggeration if I say that the pool of high-power presses a country possesses is largely indicative of its industrial level and technological potential.

We are justly proud of the tremendous achievements scored by our engineers in the field of press manufacturing. At present, the Soviet Union is the only country which manufactures giant hydraulic presses with a force of 75 000 tons".

These words of Academician A. Tselikov present the most accurate evaluation of the role of high-power hydraulic presses, the most powerful machines of today.

* * *

The designers of "Antaeus", the biggest contemporary transport aircraft, were faced with a serious problem. They had to find ways for manufacturing parts of its frame or, more precisely, its load-bearing

components. The usual manner of assembling beams, ribs, joints and spars from components joined together with bolts or rivets had been rejected as impractical, because the weight of the frame would have exceeded the predetermined limit, as it was important to keep the weight of the giant aircraft to the minimum.

It was clear that assembled units had to be replaced by monolithic parts, thus avoiding the use of thousands of bolts and rivets and their holes which are the highly stressed places and the most liable to failure.

How shall we make a part several metres long, whose surface is criss-crossed by thin and protruding stiffening ribs?

Of course, this work can be done with the aid of relatively small high-speed forging presses. The procedure is as follows: first, a huge parallelepiped-shaped blank, weighing some 3 tons, is forged similar to the monolithic stone block for a would-be sculpture. A copying milling machine then removes the excess metal and cuts the block to the required shape. Finally, a part weighing barely 300 kg and a great heap of chips containing some 90 per cent of the blank's weight is obtained.

To manufacture parts for the "Antaeus", tons of costly metal had to be removed from each forged blank, which meant wasting a lot of money, but these economic considerations were not the only argument against the above method.

Forging, as other methods of pressure forming, changes the structure of a metal by compression and thus raises its strength. A milling cutter, however, cuts through fibres of the compressed metal and reduces to zero the increase in strength previously attained by forging.

There is another way of making huge parts. One can try to force a metal blank into the cavity of a die

whose internal profile corresponds to that of a part to be made. It takes little time to finish such a semi-fabricated part by means of a cutter; metal waste is thus drastically reduced, whereas the strength of the part is not affected at all.

This way of stamping makes it possible to obtain strong blanks whose shape and dimensions are very close to those of finished parts. The effectiveness of this method would be unsurpassed but for one important drawback.

The matter is that most metals and alloys of interest to designers, as a rule, have insufficient strength, but at the same time, they almost invariably prove to be too hard for processing. Even such a simple operation as swaging requires colossal forces. Thus, to reduce by one half the height of a refractory steel ingot with a diameter of a mere half a metre, we need a force of almost 10,000 tons! A still greater force is required to compress a blank into a profiled die. Suppose hot stamping is used to manufacture parts from relatively easily deformable aluminium alloys. Even in this case a force of 20 to 40 and in some instances of 50 to 60 kg per square millimetre of a blank's surface must be applied to force the metal into each corner of the die. Now what if the surface of a blank amounts to two or even four square metres? This means that we may need compression forces of scores and even hundreds of thousands of tons.

The problem of stamping huge, complex-shaped parts is of utmost importance for the national economy. It is not only the aviation industry that needs such parts. They are also vital in the chemical industry for all kinds of giant installations, in ship-building (primarily for the frames of surface ships and submarines), in building giant power-stations, in the automobile industry, railway wagons, etc.

* * *

In the past, when there was no question of even trying to stamp large parts, the hammer was the chief pressure shaping tool.

The first steam hammer saw the light of day in 1839. It was followed by a great number of forging and swage hammers (steam and air, pneumatic, power), including those that still deafen us in forging shops. Operating hammers is uncommonly hard work, their efficiency is low and, finally, a blow dealt at a blank does not necessarily produce the desired effect, especially when forging large parts. This is due to the fact that only the surface layer of metal is compressed; the result being an uneven distribution of mechanical properties in the part.

A hydraulic press is infinitely more effective.

It is appropriate to recall in this connection an episode from "la Peau de chagrin" by Honoré de Balsac. In a desperate effort to save his talisman and his life, Raphael de Valentin rushes for help to Prof. Planchette, a mathematician and engineer.

"I want to have a pressure which would stretch this skin to infinity", began Raphael impatiently.

"Substance is finite", the mathematician put in, "and therefore may be not expanded infinitely, but pressure will necessarily increase the extent of the surface at the expense of the thickness, which will be diminished until the point is reached when the material gives out."

"Bring about that result, sir", Raphael cried, "and you will receive millions."

"To take much money is dishonourable", replied the professor, phlegmatic as a Dutchman. "I am going to show you, in a word or two, that a machine can be made that is fit to crush Providence itself in pieces like a fly. It would reduce a man to the condition of a piece

of blotting paper; a man—boots and spurs, hat, cravat, gold and all. . ."

"What a fearful machine!"

In the above episode, Prof. Planchette described most vividly the basic advantage of a hydraulic press, its capacity for developing any pressure, no matter how great.

The even and steady pressure of a hydraulic press compresses a blank throughout its entire depth, this fills the die better and improves the properties of the blank in contrast to a blow dealt by a hammer. The hydraulic press has further advantages over a hammer in that it is relatively noiseless, produces no vibration, has a comparatively simple foundation and much higher efficiency.

Paradoxically, the first working model of a hydraulic press appeared as far back as 1793, long before the steam hammer. Yet, hydraulic presses had to wait for quite some time before their advantages were fully recognized. More than half a century had elapsed before they came into use in the metal industry, a field where their services are particularly important. Previously, they had been used to bale hay, wring linen, squeeze grapes, churn butter, etc.

In our day, the field of application of hydraulic presses is practically unlimited. They are used in making chip boards and in synthesis of diamonds, in rubber vulcanization and extrusion of bars and pipes, in forming medicinal pills and stamping of aircraft parts. But, they are chiefly applied in the metal working.

Technological progress further expands the sphere of uses of hydraulic presses. Certain design features are changed to suit specific purposes, yet the operating principle remains to this day as it was formulated by Pascal in 1662: "If a vessel, filled with water and

closed on all sides, has two openings, one of which is 100 times bigger than the other, and if a piston is placed in each opening, then a man pressing the smaller piston will exert a force equal to that produced by 100 men pressing the piston whose surface is 100 times greater than that of the smaller piston".

The traditional design of a hydraulic press, evolved in the course of decades, is practically the same for any kind of press, be it horizontal or vertical, forging or stamping. Roughly speaking, it is as follows: a plunger moves under pressure inside the working cylinder (or "the greater piston", to use Pascal's terminology); the pressure being produced by a pump (i.e., by "the smaller piston"); the plunger pushes a moving cross-head sliding along guiding columns the ends of which are encased in fixed cross-heads; the bottom of the working cylinder butts against one of these cross-heads; the other fixed cross-head serving as a table; a blank placed on the table is compressed by the moving cross-head. For many years this design appeared to be the only one possible.

Two basic problems usually face designers of any type of hydraulic press. The first is making the bed sufficiently strong to withstand operating pressures. The second, to create and maintain the required pressure of the working fluid.

The 1793 press was made of wood as it did not have to sustain great pressures. However, its working cylinder was made of metal.

The first forging press appeared in 1861. All its parts were made of metal and although it developed a relatively small force of 1600 tons, its dimensions were quite impressive. Obviously, the designers did not rely much on their calculations or on the strength of materials used in those days and decided to play safe by using a very high safety factor.

In the thirties the Germans produced a 15,000-ton stamping press based on the old "column" principle, but in the course of their work, they encountered a number of serious reliability problems.

Permissible stresses in the basic parts of the press were raised to 500-600 kg per square centimetre, quite an impressive figure for large forged pieces and castings from which parts of the press were to be made. Even then the required dimensions of the columns and cross-heads were so big that the technologists found themselves in a blind alley. Just, imagine the size: each column had to be some 15 metres long and almost one metre in diameter!

To manufacture such a part was uncommonly difficult as the casting for the would-be column weighed more than 60 tons. As to the cross-pieces, it turned out to be impossible to cast them as a single whole and in the end they were made up of several specially produced castings each with a weight of 80 to 100 tons.

When the press was finally completed, it proved to be highly effective, especially for stamping various kinds of light-alloy parts. Clearly it was worth the trouble.

The building of still more powerful presses gave impetus to a great number of rapidly progressing branches of technology.

* * *

In 1943, after thorough preparation and in absolute secrecy, Nazi Germany started work on the world's most powerful press capable of developing an unheard-of force of 30,000 tons. It was revealed after the war that at one of the meetings, Hitler had described that press as "the pride of the German nation" and he pinned great hopes on that unique machine which was

to stamp large parts for aircraft, tanks and submarines. The Nazis were perfectly aware that neither the Soviet Union, nor the United States, nor Great Britain possessed such presses. But presses or no presses, nothing could save Germany from its ignominious defeat...

The 30,000-ton German press was based on the same old column principle with the only difference that it had eight columns instead of four. This was the only way to conserve the column diameter to that of the 15,000-ton press, although they had to be over 20 metres long. In fact, the new 30,000-ton press was nothing else but a combination of two 15,000-ton presses connected by a common cross-head.

After the war, a number of countries developed presses with a force of 20,000 to 35,000 tons; the United States even produced a press with a force of 50,000 tons.

The Soviet Union, on its part, built the world's most powerful presses with a force of 75,000 tons which even today remain unmatched.

The press was designed at the Metallurgical Engineering All-Union Scientific Research Institute and built at the Novo-Kramatorsk machine-building plant. The old column concept was at once rejected by the designers. The German experience with the 30,000-ton press had made it absolutely clear that the way of mechanically combining smaller presses was no longer a workable process. It was impossible to further increase the diameter of the columns and the size of the cross-heads without fundamentally reconstructing the existing plants to manufacture such big parts.

There was a need in radically new ideas.

The designers agreed on a bold solution: each of the four vertical frames was to be assembled from packs of rolled plates interconnected by studs; the moving cross-head and the table were also to be assembled from

plates. Perhaps, the word "plate" has a diminutive ring in this context, especially if we bear in mind that each such plate is almost 200 mm thick.

As regards the actual manufacturing of the press, it was, perhaps, the first example of a large-scale utilization of electroslag welding which became so wide-spread in later years. Only 7 per cent of the press' parts were cast; the fabrication of the cylinders involved both forging and welding. All the remaining components were made of rolled steel.

The original design and a number of technological innovations made it possible to produce the mammoth press without any reconstruction at the plant that made it.

The new design had necessitated a vast research program.

One of the most stress-affected area in the new press is the place where the horizontal and vertical components of the frame are coupled. It is primarily in this area that the concentration of stresses has to be reduced to a minimum. Can the composite element be made to behave like a single whole? Will the new design affect the accuracy of stamping? The designers had to answer these and a number of other questions. Special models of individual parts, units and, finally, of the entire press were built. These were used to perfect the design, check ideas and suggestions and verify calculations. A few figures will give the reader a general idea of the giant press. First, it must be emphasized that nine research centres, design bureaus and three heavy engineering plants took part in the venture. The press itself rises some 20 metres above the floor level and sinks 10 metres into the ground. The movable components of the press alone weigh 6,000 tons. These include the cross-head, 12 hydraulic cylinder rams, each with a diameter of 1.5 m, and the base plates. To

raise and lower this enormous weight and press a blank some 50,000 litres of fluid are pumped each time under high pressure into the cylinders. The weight of one die reaches 20 tons. The press is serviced by two specially designed manipulators and is controlled by only one operator seated at the central control desk.

The 75,000-ton press is an important achievement of Soviet scientists, engineers and workers.

The manufacture of large stamped parts with the aid of such presses gave a powerful impetus to the development of a number of fields of engineering, primarily, the aviation industry. The mammoth presses proved to be highly effective in stamping load-bearing elements of jumbo aircraft, parts of ships' propellers, huge ventilator blades for cooling towers and a host of other items.

It is significant that the ultimate strength of parts stamped on such presses is higher than that of forged parts by 5 to 8 kg per square millimetre. The building of the "Antaeus" aircraft is a vivid illustration of what can be achieved through such a rise in the ultimate strength; the employment of stamped parts reduced the plane's weight by several thousand kilograms.

Having produced its 75,000-ton presses, the Soviet Union became the world's leading power in the manufacturing of large-size parts by stamping.

* * *

At one time, aluminium used to reign supreme in aviation. The increased speeds of today's aircraft have imposed more stringent requirements upon their load-carrying members. As a result, aluminum has given way to other metals, titanium, refractory steels and some other unyielding and less common materials often described by technologists as "exotic". The latter are

much harder than alminum or magnesium alloys, but for their property a substantial price has to be paid. Thus, the stamping of intricately shaped parts from these materials requires a force 5 to 6 times greater than the force required for the stamping of aluminum parts of the same size and shape. This again causes an important problem, and fresh ideas are needed which would make it possible to produce even more powerful presses than the 75,000-ton giants.

The need for such presses and the drive to improve the design of the existing ones are also largely due to another important consideration that stems from the entire course of technological progress in different fields of the national economy, some of which have very little to do with metallurgy.

The use of stamped parts is so advantageous that the demand for them has grown sharply in recent years. Meanwhile, the enormous investments in the press building have raised the costs of stamped parts. To meet the growing needs of different industries and mass production we have to build presses capable of developing forces ranging from a few thousand to 30 or 50 thousand tons. It is also expedient that new presses be less bulky and cheaper than the existing ones.

What is the best way to achieve this?

When calculating the 75,000-ton giant, the designers did their best to economize on metal. Of course, they also tried to make the press as rigid as possible, because rigidity is indispensable for high-accuracy stamping. The required rigidity was attained not through the increased weight of the press, but by a number of original engieering solutions, many of which became possible by using rolled steel parts instead of cast ones.

Yet, the 75,000-ton press is a huge thing, as big as a 12-storey building.

From the experience gained it is clear that further

use of the "packet" system for building more powerful presses would make them almost as big as the Eiffel tower.

New solutions were sought. The need was to find the technical means that would revolutionize press building the way semiconductors had revolutionized radioelectronics.

One of the ways to reduce the size of the press, to achieve its "miniaturization", so to speak, is to raise the pressure of the working fluid. The greater the pressure, the lesser the cross-sectional area of ram or piston, the lesser need be the dimensions of the cylinder provided that high-strength materials are used.

Normally, the working fluid pressure in forming presses is either 200 or 320 atmospheres. The pressure is developed by pumping stations and the working fluid is accumulated under high pressure in special containers. As soon as the need arises, the press consumes a required amount of the working fluid whose reserves are then restored by the pumps. The advantage of this system is that it uses less pumps than the number required if using the maximum flow of the working fluid. It appears hardly feasible, however, to produce accumulators for pressures of more than 500 atmospheres. At the same time it should be borne in mind that a sizable reduction in the dimensions of cylinders can be only achieved by keeping the working fluid under a pressure of no less than 1000 atmospheres. In this case, the diameter of the ram would be reduced to almost half the one designed for a pressure of 320 atmospheres.

The problem of obtaining the required super-high pressure is further aggravated by a number of other obstacles.

Some of these are related to the actual uses of such a pressure. The main task in this respect is to develop

and maintain the super-high pressure in a relatively large volume of pipes and cylinders. This is due to the fact that in order to effect deformation, the length of the piston's stroke has to be kept close to 50 cm.

In addition, provision has to be made for the fact that water, although it is practically incompressible in normal conditions, loses that property under super-high pressures. As a result, the amount of energy consumed for the precompression of the working fluid is almost commensurable to that consumed for a power stroke of the press.

But this is not all. Cylinders, pipes, unions and valve boxes (used to control operating cycles of the press) have to be made of a particularly strong steel, as the enormous pressure inside them not only makes the pipes "heave", but also changes the properties of the metal. To select an appropriate steel is not easy, it has to be welded and weldable steels are known for their relatively low toughness. When it is borne in mind that each press has hundreds of metres of pipelines and scores of valves that must be 100 per cent leaktight, it becomes absolutely clear that the practical application of super-high pressures had to be preceded, first, by comprehensive research in different fields and then, by working out appropriate designs. To obtain such pressures, special pressure multipliers were produced which operate as follows. A pumping station supplies working fluid under a pressure of, say, 320 atmospheres, to the large cylinder of the multiplier. The plunger of this cylinder moves synchronously with the smaller plunger that forces the working fluid from the smaller cylinder of the multiplier to the press. The acting areas of the plunger are selected so that the pressure of the working fluid passed to the press is increased to, say, 1000 atmospheres.

This principle is not new but the significant fact

is that the Soviet multipliers were capable of producing pressures of 1000 and 1600 atmospheres with a fluid capacity of 300 litres per one working stroke of the press, the duration of which is not more than 15 or 20 seconds. (It has to be remembered that first the fluid must be compressed and then the press ram can move.) Another important feature of these pressure multipliers is that they for the first time incorporated packing made of polyamide materials, which were 100 per cent leakproof at the super-high pressures.

The game was certainly worth the candle as in the press operating under 1600 atmospheres the dimensions of its ram were able to be reduced by more than a half, as compared to the press operating under 320 atmospheres.

However, 1600 atmospheres is not the limit. Work is currently under way to conquer a new peak of 4000 atmospheres.

* * *

When designing a press, to solve the problem of the working fluid pressure is only half the work. The remainder consists in producing a compact bed which, although dimensionally small, could withstand tremendous stresses.

In the late fifties, engineers believed they had found a rational principle of a bed which could withstand any forces.

Engineers at the Novo-Kramatorsk machine-building plant and the Metallurgical Engineering All-Union Scientific Research Institute designed presses with beds made as very large pipes (monolithic or composite) in contrast to the frame-shaped beds used previously, with the working cylinder placed at one end.

It seemed advantageous to have only one cylinder,

as this automatically reduced the size of the press, although the cylinder had to be uncommonly big, close to 2 metres in diameter. The manufacture of such a cylinder was indeed a complicated technological affair, the more so as the pressure of the working fluid inside had to reach 1000 atmospheres. (This was the limit at the time, and incidentally, the one-cylinder press as such only became feasible because the 1000 atmosphere pressure could be obtained.)

The problem was further aggravated as the cylinder had necessarily to be fitted into the limited space of the tubular bed. Owing to the enormous pressure of 1000 atmospheres the cylinder was made of high-quality alloyed steel. Even then metallurgists could not fully guarantee the steel's quality in view of the tremendous complexity of forging the mammoth cylinder.

What if the cylinder is suddenly out of action? This would mean dismantling the entire press. Besides, it is far too expensive to hold, as a spare, a working cylinder of this type. The main disadvantage of this unique and highly expensive machine was that occasional breakdowns, resulting in long idle periods, could not be avoided.

In addition, the dimensions of the tubular bed are limited by the production facilities; it has to be forged, heat treated and transferred from one machine-tool to another, and then transported to the assembly site.

Numerous experiments and calculations indicated that building a "tubular" press capable of developing a force of over 30,000 tons was practically impossible.

Finally, such presses can only serve a limited number of purposes. In other words, they can only be used for stamping relatively small flat parts. The working stroke of the press is limited (hence, its reduced height) and the loading openings in the tubular bed are also small, so large-size blanks cannot be put in the press.

The "tubular" presses built in the late fifties at the Novo-Kramatorsk machine-building plant develop forces of 15,000 or 30,000 tons. Regretfully, the experience gained in the course of their operation has made it absolutely clear that their underlying principles are impractical, and this design cannot be used for superpower presses.

* * *

For a press to develop a colossal force and have a comparatively low weight, its bed has to be made of high-strength materials. This is obvious and was the case with the "tubular" presses, which, nevertheless, did not meet their designers' expectations. The reason is clear: the strength of forged parts, especially of large-size ones, leaves much to be desired. Their yield limit is never higher than 30 to 35 kg per square millimetre. This is in any case less than desired.

The result is a vicious circle: whatever design was suggested, it was invariably vetoed by the weakness of material.

Meanwhile, as is often the case in engineering, the solution had been already found, although it was utilized for purposes infinitely remote from the subject of our discussion.

In ancient Rome, grape pressing was done by means of screw presses which were wound around with ropes for greater durability. Early in this century, Great Britain produced artillery pieces wound with wire. During the Russian Civil War, guerrillas in Siberia used canons with barrels made of wire-wound oak planks. In our day, engineers in Sweden have been making presses having parts reinforced by this method.

Yet the potentialities of such a construction had never been used to the full. The experience gained in

this field had to be thoroughly studied and further developed.

The strength of a thin steel strip is 6 to 10 times higher than that of large-size forged parts of weldable steel. This promises sparkling possibilities, primarily because reinforcing the parts of a bed with a high-strength strip ensures optimum loading conditions for the press.

The columns, or pillars, of a press built according to the traditional scheme are subject to stretching. Tensile stresses, which are particularly dangerous for press components, also occur in the cross-heads. When wound around with steel strips, these components are initially stressed and compressed to a certain extent. With the press in operation, the result is that tensile stresses never exceed those of compression.

The advantages of this method can hardly be overestimated. Even if parts of a press are made of defective forgings, they can withstand stresses almost three times higher than those normally observed in conventional presses. Moreover, this method even makes it possible to use cast cross-heads and pillars; their relatively low strength in no way affects the size of the press. The utilization of cast blanks is highly advantageous. First, these are cheaper than forged parts. Second, their finish is in no way a lengthy process involving sophisticated or even unique metal-cutting machine-tools. Machining allowances for cast blanks are substantially lower than those for forgings.

Hence, only the steel strip is under tension, which, taking into account its high strength, will never give way, even if the tensile stresses are higher than those normally permissible for the components of a press.

Strictly speaking, the use of a steel strip is not the only way of prestressing the bed. In the case of a "column" press, the same effect may be produced by

tightening the nuts. However, reinforcing parts of the press with several wound layers of steel strip is infinitely more reliable.

Take, for instance, mine shaft hoist, the one that carries people. Its cable has to be absolutely reliable; hence, the stringent requirements imposed upon it. One may be surprised to learn that such a cable is still considered good even with up to six strand ruptures per metre of its length. This is a good example of the reliability of what is referred to as a "multicomponent structure".

It is also notable that strip winding, although uncommon in machine-building, presents no special difficulties. For smaller presses, it can be done on ordinary vertical lathes.

A high-power press having proportionately large dimensions is transported to an assembly site in a dismantled state. Upon their arrival, the vertical components of the bed (pillars) and its horizontal components (beams) are joined together to make a frame. A reel of steel strip is moved around the frame by a special device, leaving layer after layer of strip upon its surface. The winding is done under slight tensioning.

Upon completion of the press assembly, a pressure is applied which is above the normal. It stretches the frame and the resulting gaps between the beams and pillars are wedged with packing. The pressure is then removed leaving the strip under tension thereby compressing parts of the bed.

Unlike a "tubular" press, the designer is now free to select any position for a die whose dimensions are only determined by the specific purpose.

The new design also makes one free to select any number of working cylinders, which may be one, two, four, etc.

This has a number of advantages. It is quite economic, for example, to have one spare cylinder per several working ones.

A little more statistics. It used to take almost 6000 machine-hours to manufacture a "tubular" press with a compression force of 15,000 tons. This figure will be halved for a 16,000-ton press manufactured at the Kolomenskoye heavy machine-tool plant near Moscow.

It should be added that under equal conditions of compression, working fluid pressure, etc. the press with a steel strip winding weighs less than the "tubular" press.

The fact that the new-type press evolved by the Metallurgical Engineering All-Union Scientific Research Institute has a sectional bed opens up boundless possibilities for producing presses capable of developing any force, no matter how great or small. In conclusion it should be said that the original design of the press has won its authors several Inventor's Certificates.

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It is absolutely clear now that tomorrow's superpower presses developing a force of a hundred, five hundred thousand or even a million tons will be based upon the above principle.

It is also clear that a powerful hydraulic press of the new type can be installed practically at any machine-building plant. Another important feature about such presses is that they need not be built at giant engineering works; their construction can be coped with just as effectively by smaller enterprises.

Today, the Soviet Union already has several 2000-ton presses. This figure seems insignificant unless it is taken into consideration that such a press weighs only eight tons and is only the height of a man. A "tubular"

press developing the same force is 4 times as heavy and twice as high.

The 2000-ton presses are now being mass produced and a more powerful, 16,000-ton press is being evolved.

According to calculations and research data, the use of the new design for a press capable of developing a force close to the present-day 75,000-ton limit would reduce the height of the original design by some 15 metres and cut down its weight almost six times, that for each individual machine would save thousands of tons of metal.

Soon we shall no longer regard a high-power hydraulic press as a unique machine. While retaining all its titanic power, it will cease to be a giant.

It may be said with certainty that hydraulic presses are entering a new highly promising stage in their evolution.

AGROBRIDGE, A GIANT AGRICULTURAL MACHINE

A machine which will revolutionize agriculture

With all its specific features, it does not seem that agricultural industry needs giant machines. Indeed, the country-side has never seen such machines. This does not mean, however, that they are not necessary, which is corroborated by a great number of more or less rational designs.

A giant water sprinkler, a characteristic example was described in the American press. An enormous metal truss, over a kilometre long, is to be placed in the middle of a field which requires water. The truss is supported at its centre by a huge ferro-concrete structure into which water is pumped under a high pressure. In addition, the truss rests upon a number of wheels

and caterpillars spaced along its length. The water drives hydromotors which rotate the giant truss, one revolution taking several hours. The water leaving hydromotors passes to jets and is sprinkled upon the field.

A highly original design of a giant agricultural machine has been evolved by M. Pravotorov of the Soviet Union. Referred to as the agrobridge, or bridge cultivator, it will most likely in the future successfully compete with the tractor.

The inventor first brought forward his idea more than 40 years ago. In April 1931, the Central Inventions Bureau under the USSR People's Commissariat of Agriculture passed a resolution on the setting up of a special committee to translate that idea into reality. Soon, however, the invention had to be shelved. There were two reasons for this: firstly, contemporary engineering was not yet sufficiently advanced to cope with the invention and, secondly, at that time the nation was unable to back it financially. World War II relegated the invention, like many other things, to the background. Still M. Pravotorov never gave up his idea, but, on the contrary, continued to perfect it and enrich it with the latest achievements in agronomy, cybernetics and agricultural machinery. Today, it has the full backing of a great number of scientists and engineers and is often featured in agricultural publications. Recently the journal "Khlopkovodstvo" ("Cotton Growing") reported that first steps had been taken to put the idea of the agrobridge into practice.

Designers are doing their utmost to increase the operating widths of agricultural machinery, but these possibilities are limited. Increased operating widths call for more reliable machinery and improved field leveling. In addition, this tends to augment the weight of tractors and other machinery. As a result, the soil

is subjected to a growing unit pressure, which acts adversely upon its structure. Besides, such a relatively small machine as the tractor cannot fully incorporate all the latest achievements in automation and telemechanics, or use radioactive radiation, magnetic and electric fields in order to stimulate the growth of plants. The bridge method should obviate all the above disadvantages.

M. Pravotorov's idea is very simple and boils down to a large-scale utilization of the bed system. A field is divided into beds which, unlike the narrow ordinary beds, are 50 or even 100 metres wide. All work is done by the bridge machine, a 100-metre-long metal truss resting upon two caterpillar tractors that move along balks separating the beds. Depending upon a job to be done, the truss carries different implements. For ploughing or cultivation, it carries motors with rotary cultivators; for sowing, it carries seed and fertilizer distributors, sprinklers, etc. Each machine the truss carries is independent of its neighbours and is automatically lifted or lowered to suit the terrain.

The balks along which the caterpillar tractors move are actually good hard roads; thus, going up and down the fields which turn into almost impossible mires in spring and autumn is no longer a necessity. As a result, field work can be started earlier than usual and does not have to be interrupted because of bad weather. In the south of the Soviet Union, two harvests could be gathered instead of one. For the balks to be made into roads they have to be leveled, covered with a layer of crushed stone and cement which is then coated with a centimetre-thick layer of bitumen. The roads will be flanked by graduated metal rules. These will enable photoelectronic devices to orient the bridge, so that the coordinates of each machine or implement will be known to an accuracy of a few millimetres.

Thus, all field work may be automated, including harvesting. Planting will be done in a certain order, and the coordinates of each plant will be recorded on a magnetic tape. Using these recordings, control instruments will set into action machines that will loosen and moisten the soil and give every plant its portion of fertilizer and doze of radioactive radiation, destroy weeds by hot steam and do a host of other operations in accordance with a programme worked out by agriculturists and biologists.

Such a method, combined with full automation, will make it possible to take care of every individual plant with regard to all the peculiarities of its growth. This should, in turn, fantastically increase the yield of the plants. Such meticulous care of every individual plant has at some experimental plots increased the yield per hectare of grain to 150 centners and that of potatoes and sugar-beet, to 1500 centners.

At present, only one culture is raised in each field. In natural conditions, however, plants grow pell-mell, but mutually adapt themselves to one another to make better use of moisture, sunlight, air and nutrients. Growing monocultures is not a biological necessity, but is dictated by the limitations of the present-day agricultural machinery and methods of land cultivation. However, the memory unit of the agrobridge knows the exact location of each plant, it can selectively treat and harvest each culture. As it moves along a 100-metre-wide bed sown with, say, buckwheat, potatoes, peas and wheat, the bridge can selectively spray, fertilize and harvest each of these cultures. As a result, the yield per unit area will sharply increase.

The idea of the agrobridge is simple and readily understood. Its design, on the contrary, is rather complicated. The bridge framework is made of steel tubes and girders, aluminum and plastic pipes, sheets and

jackets. It has an engine room and is divided vertically into three tiers.

The engine room houses gas-turbine engines or electric motors if there is a power line nearby. Gas-turbine engines are advantageous as they develop a colossal power output in spite of their small size and weight.

The lower tier of the bridge carries platforms with agricultural implements placed on them. Each implement is lifted or lowered hydraulically to suit the terrain, and cultivates a 5-metre-wide section of the bed.

The middle tier houses the "heart" of the circulation system. Glass and plastic pipes feed water, chemicals, steam, compressed air and carbon dioxide to sprayers and atomizers, and when harvesting, conveyors transport grain and vegetables and load them into trucks.

The upper tier is a repair shop. It is provided with gantries and hoists which are used in the repair and assembly of large units. In the middle of this tier is a deck-house, the "brain" of the agrobridge, full of control instruments, mechanisms and compact computers. It is a comfortable cabin with a panoramic view.

From the point of view of agricultural production, M. Pravotorov's idea is an interesting illustration of how fundamentally new machines and technological processes may be introduced into the farming, one of the oldest fields of human endeavour.

The idea is backed by a number of leading agricultural experts. Academician G. Koshevnikov says it is high time research institutes started practical work in this field. Specialists believe that the present-day level of machine-building, materialogy and automation makes it feasible to effectively build agrobridges with a substantial operating width.

MIDGET MACHINES WITH HUGE PRODUCTIVITY

Rolling mills produce balls, bushes, drills and finned pipes

A few years ago designers at the Novo-Kramatorsk machine-building plant had completed work on a special order, a giant rolling mill of the 4200 model. It was estimated to cost 50 million roubles and weigh 30,000 tons. A huge building to house the mill was to be erected in Lipetsk, an industrial town in Central Russia. The work had to be done as soon as possible, for the mill was to produce metal sheets with a width of 4200 mm which were badly needed for gas pipelines. However, when the design had finally been completed, the building of the mill was suddenly cancelled. In fact, the new mill was no longer needed, for it had been found by that time that large-diameter pipes could be made of narrow steel band by means of spiral-seam welding.

The weight, size and workspace of an installation implementing the new method were very much less than those of the rolling mill. It is most instructive to study numerous instances when the introduction of improved technological processes has made it possible to replace mechanical giants by smaller machines, thus saving millions of roubles.

Open-cut mining has become quite common in recent years. However, scores of millions of cubic metres of earth have to be removed to expose a coal seam or ore bed. This heavy work is done by giant digging machines the efficiency of which, as a result of the designers efforts, is steadily increasing. This, in turn, complicates the transportation problems. A modern rotary excavator extracts as much as 3000 cubic metres of earth per

hour. To carry away such an enormous amount of earth within an hour, means employing 200 40-ton MAZ* dumpers, and every twenty seconds a dumper has to be loaded, clearly an impossible task.

Instead of a long row of trucks taking away the earth extracted by an excavator, mining engineers increasingly resort to rolling bridges, i.e., a system of movable carriers mounted on strong metal girders. The farther the rock is to be removed, the more impressive the size of the rolling bridge. A bridge 100 m long weighs 1200 tons. A 200-metre long girder weighs almost 3000 tons; it incorporates 1500 roller supports, 3000 ball bearings, 500 to 600 metres of high-strength rubberized conveyor belt and many other details. Such a bridge costs more than 1.5 million roubles.

The increase of excavator efficiency must necessarily be accompanied by an increase in the sizes of roller bridges, but how far can this process continue?

An end has been put to the ever increasing size of the bridges by an invention made by two Kiev engineers, A. Degtyarev and S. Vinogradov. They suggested that discarded turbojet engines be used to transport rock.

The powerful exhaust jet of such an engine is directed into a steel pipe 7 to 8 metres long and about half a metre in diameter. From a feed bin above, the same pipe is loaded with rock extracted by the excavator. The jet of hot gases blows pieces of rock, which may be as big as 150 to 200 mm, and throw them out over a distance of 200 metres.

One such installation handles 4000 cubic metres per hour and is powerful enough to serve a largest rotary

* MAZ is a model of a dumper currently produced at the truck works in Minsk, capital of the Soviet Republic of Byelorussia.

bucket excavator. It is infinitely smaller than a roller bridge and weighs 150 times less, only 20 tons.

The use of the highly efficient, light, and compact jet rock transporters opens up new prospects in mining. According to a number of specialists, they will be extensively used when working the world's biggest iron ore deposits discovered near the town of Kolpashevo in Siberia. The ore bed in that area is 10 to 15 metres thick and stretches over thousands of square kilometres at a depth of 100 to 150 metres.

The digging machine model ZFM-3000 designed by a group of engineers at the Hydroengineering Research Institute and the All-Union Civil Engineering and Road-Building Scientific Research Institute is another example of an ingenious technical solution. The amount of metal required for its construction is a mere 10 per cent of that used for a conventional digging machine; at the same time, its operating costs are cut three or four times.

Unlike a bucket excavator, the ZFM-3000 is designed to excavate continuously, this helps to avoid uneven alternating loads in its units. Each unit of the machine does one specific job; as a result, the machine is simple in design and highly efficient.

The working member of the machine consists of six two-metre cutters mounted on a horizontal shaft. The cutters are placed at an angle to one another and do not cut into the ground all at the same moment, thus assuring the smooth operation of the machine.

The excavated earth is thrown onto a scoop and passed to removing belt conveyors. The new machine transfers 3000 cubic metres of earth per hour, moves at a speed of half a kilometre an hour, and leaves behind a ditch three metres wide and almost two metres deep. To equal this would require 4 or 5 excavators with a bucket capacity of 5 cubic metres and a

total weight of 1000 tons; the ZFM-3000, however, weighs only 100 tons.

Of course, the digging machine cannot in all cases replace the excavator, but the weight ratio is certainly in favour of the former.

* * *

Perhaps, the most striking example of reducing the overall dimensions and weight of equipment with an increase in efficiency has been attained by means of a new technological process introduced into rolling.

Today's metal-working process hinges on casting, cutting and pressure-forming. The three processes complement one another. Castings are cheaper than forgings, but are inferior in strength. In most cases, both have to be machined to remove excessive metal and obtain the required dimensions.

It is perfectly natural for highly stressed parts vital for service life of a machine, to be produced by forging or stamping. At the same time, production engineers are interested in minimizing metal waste and production costs.

Stamped blanks are, doubtless, preferable to forgings as less metal is wasted in the form of chips. Yet, stamping, too, has a number of disadvantages. First of all, dies are highly expensive. Unless used for mass production, stamping is apt to raise the cost of parts. Of course, some parts are in great demand and have to be produced by hundreds of thousands and even millions. Here too, an equally serious problem arises. The point in question is the efficiency of machinery. In fact, when forging by a hammer, several blows are necessary. In the case of a press, this requires several strokes and even high-speed crank presses cannot operate faster than 60 strokes per minute. True, these are forging-and-

stamping automatic machines fabricating bolts, nails and ball bearings which work at a rate of several strokes per second but these are to turn out astronomical quantities of details. In addition, such a rate of operation brings a machine very close to its ultimate working limit.

It is clear then, that neither a hammer, nor a press, nor an automatic stamping-and-forging machine, in short, none of the machines that are used for stamping or forging are able to turn out parts continuously. A certain amount of time is inevitably lost in idle strokes.

Meanwhile, the above and other disadvantages are absent in one of the existing methods of pressure forming. This method is rolling. Compared to forging, rolling is a new method, for it was first introduced less than 300 years ago. Items produced by rolling range from foil with a thickness of a few microns to sheet metal and armour plates. Rolling is the most productive way of turning out different diameter pipes, metal sheets, angles, channels, I-beams, etc. Most machine parts have variable cross sections. Rolled items, however, have the same shape and dimensions within certain limits over their entire length. This was a serious obstacle to enthusiasts who wanted to roll machine parts of different sections. A group of rolling experts at the All-Union Metallurgical Engineering and Scientific Research Institute concluded that this task, although extremely difficult, was feasible. They started by studying the requirements of different industries and pinpointed the most badly needed parts. They reasoned that, keeping in mind the high productivity of rolling one or two rolling mills, or a dozen at most, would be enough to meet any demand, no matter how great it is. They also realized that idle periods would lower the economic effectiveness.

Having selected the specific details to be produced, the group set out to evolve fundamentally new rolling methods, for none of the chosen items could be produced by the existing methods. The engineers had to eradicate many dogmatic concepts to attain their goal.

Many years had passed before the new trend in rolling practice initiated by Academician Alexander Tselikov, a leading Soviet scientist, was universally recognized both at home and abroad. Due to this work there are now more than 40 rolling mills of an unusual design in the Soviet Union.

* * *

The production of spherical objects by rolling at first seemed impossible; but notwithstanding this fact, mills designed especially for ball production were the first to use the new-type machines and to revolutionize rolling. Industry needs millions and even billions of bearing and grinding balls; hence, balls were chosen to be mass-produced by rolling.

Like conventional rolling, a blank, which is a hot metal rod, is passed between rolls, but here the similarity ends. The surface of the rolls is not smooth, like in ordinary rolling, but is screw-shaped, with a variable profile and pitch. Rotating towards one another, the screws engage the rod. The rod also starts rotating and, while moving along the roll, is gradually squeezed. The roll grooves become increasingly spherical, and the rod is gradually shaped into a series of balls connected by the reduced diameter of the rod. The last groove in the roll sizes and parts off the finished ball.

Each revolution of a single-thread roll produces one ball. Double-thread rolls and those with three and four threads were then evolved; each revolution of these

turns out two, three and four balls, respectively. Taking into account the high rotational speed of the rolls, it is clear why such a machine is 8 times more productive than the most efficient automatic stamping machine.

The new machine produces a variety of bearing and grinding balls; the diameter of the former ranges from 25 to 50 mm and that of the latter, from 40 to 125 mm. The high efficiency in no way affects the quality: errors never exceed one per cent of a ball diameter.

In this machine, particles of the bar describe a helicoid as the bar moves forward, it also rotates. Hence, the name of the new process: cross-screw rolling. As we shall see, this method has made possible the mass production of a large number of different items.

It has been already noted that owing to the amazing effectiveness of the new method, only a limited number of rolling mills of the new type is needed to satisfy all demands. Generally, a research institute which devises a new machine only makes a prototype, often with the aid of appropriate industrial enterprises. Here, on the contrary, the All-Union Metallurgical Engineering and Scientific Research Institute not only designed the new machines, but also produced the required small number. The task was further facilitated by the small weight of these machines. The new machines are indeed very small as compared to the mammoth conventional rolling mills weighing thousands of tons.

* * *

Profiled shafts are some of the most commonly used parts in engineering. They are used as axles and axle shafts in cars, trucks and tractors, spindle arbors in textile industry, electromotor shafts, railway wagon axles, etc. The above list is indicative of the tremen-

dous quantities of these parts used in different industries.

Here, too, the problem has been solved by the introduction of cross-screw rolling. Again the new machines devised for the purpose have nothing in common with conventional rolling mills. Although very efficient, they are infinitely smaller compared to rolling mills occupying whole buildings with powerful mechanisms. The new machine is compact like a lathe. Inside it, there are three tapered rolls equally arranged at angles of 120° relative to the hot bar which they compress.

The variable profile of the details introduces a new element into cross-screw rolling. As a bar moves forward, the gap between the rolls is changed to produce the desired profile. To control this process, the machine is provided with a special follow-up system. A steel ball is fixed on the end of a rod of a hydraulic cylinder which controls the movement of the rolls. The ball slides along the profile of a master form which is a replica of the shaft to be produced. On encountering a recess the ball slides into it and changes the position of the hydraulic cylinder rod which delivers oil to the rolls. The rolls move closer together, thus forming the required neck in the shaft. When the ball encounters a step on the master form, oil is driven to the other cavity of the cylinder, the rolls move apart, and a step is produced. The rolls work like a sculptor and shape the desired profile.

Five such machines are currently in use at a textile engineering plant producing textile equipment in Kolomna near Moscow. Their performance is such that despite their small number they satisfy the demands for spindle arbours of the entire textile industry in the Soviet Union. One machine at the Komsomol Automobile Works fully satisfies the needs of that huge enter-

prise for axle shafts saving by this method on each detail 25 per cent of the metal previously wasted in the stamping axle shafts.

The new machines are practically universal. By changing the master form, they can be used for the production of many different designs of components.

Today we already have rolling mills which turn out blanks for socket wrenches, electromotor shafts, tractor axle shafts and a great number of other items. Cross-screw rolling is not confined to the fabrication of solid items. The same principle is employed in machines which produce hollow billets, profiled pipes and all kinds of bushes.

Let us take bicycle hubs as an example. These are made as follows. First, a two-metre long sleeve is broached on a double-roll machine. Before the sleeve cools down, it is passed on to rolls with a threaded profile. These turn the sleeve into a rod which consists, like a bamboo stick, of separate sections. The sections are then cut off and machined on lathes. Only one millimetre of metal is removed. As a result, the production of one thousand hubs consumes 250 kg lesser metal than when they were forged on a horizontal press, which had been regarded previously as the most up-to-date and efficient method. Again, one machine satisfies the whole national demand for bicycle hubs. It produces over 3 million hubs a year.

Today, researchers and designers are already solving the problem of producing a mill for rolling tubular railway wagon axles, which will replace the large number of lathes currently doing this work.

* * *

Among the parts for which the demand is very large are those that cannot be produced by forging and

stamping. Most of these are virtually carved from a piece of metal with the aid of different machine-tools, whereas some require still more sophisticated and costly processes in their manufacture.

The progress in chemistry and its allied fields, for example, calls for an ever increasing demand in pipes made of light alloys having a multitude of projecting, thin and closely placed fins. These are badly required in the manufacture of coolers, heaters, heat exchangers and other apparatus of this kind. Until recently the fabrication of such pipes was an extremely difficult process: fins specially made of wire were soldered onto smooth pipes. The demand was never fully satisfied until cross-screw rolling came to the rescue. The new process is as follows. Mounted on three smooth rolls is a set of discs whose combination makes up a threaded profile. This profile produces from a plain smooth pipe a tube having an inner diameter of 10 to 35 mm and ultrafine open fins on its outer surface. The productivity of the new rolling machine is extremely high and amounts to 200 linear metres of pipe an hour. The weight of this machine is very low, being only a few tons.

Meanwhile, the All-Union Metallurgical Engineering and Scientific Research Institute is completing work on an improved version of this machine which will turn out 500,000 linear metres of finned pipes a year.

* * *

Until recently, tools were manufactured solely by cutting, but this monopoly was broken by rolling. The first task undertaken by the specialists was the production of one of the most intricately shaped tool, the drill. Even a passing glance at a drill is enough to convince one of the impossibility of manufacturing it by rolling.

Indeed, its shape is so complicated and so absolutely different from the components already produced by rolling that the task seemed to be almost unsurmountable when designers started to work on the problem. A speedy solution was necessary because of all metal-cutting tools, drills are mostly needed and in the largest quantities. The milling capacity was clearly inadequate to satisfy the demand. The only way to increase the production capacity seemed to be the building of new production shops, increasing the number of machine tools and alas! the piling up of additional heaps of waste metal chips, because the conventional drill manufacturing process turns into chips no less than half of the valuable high-speed steel originally contained in a blank.

In this connection it should be said that none of the newly evolved rolling methods, including cross-screw rolling, appeared fit for drill manufacture. After long research designers finally built a complex of four rolls. One pair was placed horizontally and the other, vertically. The rolls in each pair were arranged at an angle to each other, like the blades of a propeller, each pair having a specific task: the first pair rolls grooves and the second pair rolls the back clearance. One pass is sufficient to change a blank, heated by high-frequency current, into the shape of a drill. From this it is seen that the effectiveness of longitudinal-screw cutting (as the method is called) is astonishing. The new machine produces up to 20 relatively small drills per minute, or 5 drills with a diameter of 25 mm and a length greater than one third of a metre. This is 10 to 15 times more than the output of the best automatic milling machines, and metal waste during finishing is 20 to 30 per cent less than that of the previous conventional method. In addition, the drill is of a finer quality and its service life substantially longer.

* * *

There is still another machine detail which cannot be ignored when speaking of large quantities. This is the gear wheel. It is impossible to think of any machine without gears. In the Soviet Union more than half a million gears are produced every day.

Gear-cutting machines are, perhaps, the most sophisticated and the least productive of all metal-cutting machine-tools. This is not because gear-cutting has not kept abreast of the times. On the contrary, for 100 years since the "birth" of the first gear, gear-cutting has achieved a high degree of perfection. The reason lies in the principle which is the basis of the process, i.e., the need to cut metal in order to generate teeth.

It would be wrong to say that no attempts were made in the past to manufacture gears by other methods than cutting. At one time, casting seemed to be appropriate for the purpose, but cast gears were not sufficiently accurate and mass production thereof was found impractical.

Again rolling provided an answer. It was found that the plastic deformation could be used to form unlimited quantities of gears having a number of fine properties when pressure forming is employed: their strength increased by 30 to 40 per cent, while the amount of metal required for their production decreased by 20 per cent. As in the previous example, the machine used to manufacture such gears resembles an ordinary lathe. Pre-heated blanks with a somewhat lesser diameter than that of the would-be gears are held by a smooth, cylinder-shaped chuck and passed between gear-shaped rollers. Under the rolling pressure, the metal gradually fills the recessions between the teeth of the rolls and in 4 or 5 seconds the gear is formed.

On a gear-cutting machine the gear forming process takes 7 to 8 minutes. The new rolling mill giving a multiple increase in productivity certainly deserves a name which would better convey its amazing purpose. Of course, when a gear has to be highly accurate, it is finished by grinding but most gears, especially those with a large modulus, are fit for use straight after manufacture.

In this chapter, we have dealt with only a few original rolling mills, small in size and great in productivity, that have been evolved in the Soviet Union. Owing to the very limited volume of this book, the well-known HPTR mills (a cold-rolling tube mill), as well as a number of other mills manufacturing screws, worms, sprockets, milling tools, etc. cannot be described here.

The above and a number of other machines are based on the original ideas put forward by A. Tselikov, S. Granovsky, E. Levin, I. Pobedin, S. Milyutin and other Soviet scientists and designers. All these men have been granted Inventors' Certificates.

In conclusion, the author would like to mention one interesting fact which testifies the high level of miniature rolling mills produced in the Soviet Union. Great Britain, one of the world's leading exporters of rolling machinery, is currently purchasing rolling mills evolved at the All-Union Metallurgical Engineering and Scientific Research Institute.

THE NEEDS OF "GULLIVER"

Technological requirements of giant machines

As we have seen, certain giants of the mechanical world have turned into dwarfs. These transformations, however, have only been observed in a limited number

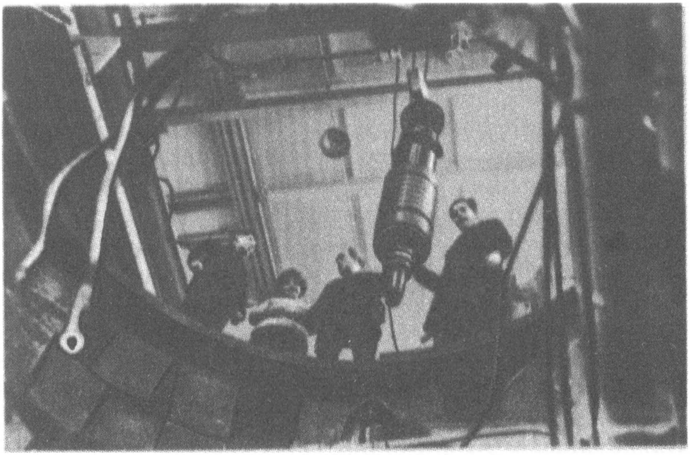
of instances. It is often the case that the giant machines prove to be sufficiently economical and well serve their purposes, so that we have to put up with all sorts of inconveniences resulting from their enormous size and weight.

Remember the adventures of Gulliver in the land of the Lilliputians. It was a major problem for the poor tiny creatures to feed, clothe and find a place for the man, built like a mountain, to live.

The situation is much the same in building and operating superheavy machines. The manufacturing of components and units, heat treatment, inspection, transportation to a site and assembly, these are all extremely laborious tasks because of the huge size and weight of these machines. The ingenious devices and techniques used to overcome these difficulties would make an interesting chapter in the history of machine-building.

In a previous section, we have mentioned the colossal forces of 75,000 tons developed by hydraulic presses. Today, some engineering problems call for even greater forces. One factory, for instance, recently had to stamp a large cylindrical billet. For this a new stamping method, known as thermopressing, was especially devised, it uses the gigantic forces arising from thermal expansion. According to one of the theories expressed in strength of materials, the force exerted by compressed heated rod is equal to the product of the elasticity modulus of the material by its linear expansion coefficient, the area of the rod's cross section and the difference between the temperatures before and after the heating. By heating a chrome-nickel 10-cm steel cube for a few seconds, a force of 1000 tons is obtained. No equipment is practically required for the purpose.

Special installation, called a thermal press, was designed; it consists of a massive steel ring surrounded



A blank, which is a massive steel ring, is placed on the bottom of a concrete well and set into fast rotation during which it is stretched by centrifugal forces and converted, in a few seconds, into a finished part

by a layer of a heat-insulation material and is lowered into a well. The ring is heated up to a stamping temperature which is kept constant. Inside the ring is placed a cold tubular blank, inside of it is a massive metal ingot which serves as a drift. The outer lateral surface of the drift contains splines, i.e., ribs and grooves inverse to those to be impressed on the blank. After the drift has been set in its operating position, it is heated. The drift expands compressing the blank and forcing its metal to fill every recess on the drift. For this process, induction heating by alternating current is preferable. The arising eddy currents oscillate at a frequency of 50 cycles per second and vibrate the blank. The vibration reduces the metal friction be-

tween surfaces of the blank and the drift reducing substantially the required squeezing force. On completion of the process, when the metal has filled all the spaces of the splined drift, cooling liquid is fed through channels drilled in the drift. The drift is compressed again and easily extracted from the outer ring, i.e., the container together with the finished part. The cooling continues, and in a short while the formed component slides off the drift. Its inner surface, like a wafer, contains a network of grooves, ribs, recessions, bosses and swells. It is impossible to obtain a tubular part having profiled inner surface by any other method. At any rate, no other method proved to be effective. Engineers tried sectional stamping which consists in stamping a flat blank section by section, after which it is formed into a pipe and welded. Between blows of the die, however, the blank cooled down and had to be reheated, because of this dimensions altered and the required form was distorted beyond reasonable limits. Rolling has also been tried and also without success, since it inevitably led to the appearance of cracks under cross ribs.

As regards casting, it is common knowledge that the strength of cast parts is less than that of stamped parts. Hence, thermal pressing is this far the best method. When pressing tubular billets of aluminum or magnesium alloys 2 m in diameter and 1.5 m high, the compression force amounts to a quarter of a million tons. To increase this value three or four times, present no difficulty. The method dispenses with separate heating furnaces, because a thermopress incorporates both the compression and heating units. The thermopress has at least two important advantages over its conventional counterpart. Firstly, it is extremely simple in design, for it has no moving parts, no bearings, pumps, or pipe systems. Secondly, it requires immeasurably less metal for its construction. A conventional press capable of

developing a force of 50,000 tons weighs 15 to 20 thousand tons, whereas the weight of a thermopress of the same power only amounts to 25 or 27 tons, i.e., one thousand times less! True, its capacity is not so high, it takes almost two hours to manufacture one part, but several such presses may be placed in a shop and they can all be serviced by one overhead crane. The size of parts they turn out is practically unlimited, the greater the diameter of a part, the greater the thermal deformation of the drift and the easier becomes the stamping process. In practice, the new method has its greatest efficiencies when the diameter of a component is over 50 cm.

A method no less unusual than thermopressing has been evolved at the Central Research Institute of Technology and Machine-Building for manufacturing large-diameter bushes known as caps.

Caps are fitted on the rotor shafts of generators at steam power stations. Their purpose is to prevent the centrifugal forces from tearing the winding of the rotor from its grooves and thus put the generator out of action. Until recently failures of this kind had been a nightmare for power engineers. A tragic accident took place in Canada when a burst cap caused the death of a team of experts who were to commission a new generator.

Normally caps are made of austenitic steel by gradually compressing annular ingots on a hydraulic press. By this method, it is impossible to obtain an even distribution of mechanical properties over the entire volume of the part. This is the basic cause of the caps frequent failures.

In the United States, attempts have been made to manufacture caps of magnetic steel which is more easily shaped by pressure. This steel, however, has one serious disadvantage, it produces eddy currents in the

generator. To obviate this disadvantage a larger rotor and special insulation materials were used which reduced the generator efficiency. The engineers were in a blind alley, especially when building high-power generators with an output greater than one million kilowatts which, it should be noted, remains to this day the most economical output.

Size capacities at most plants are insufficient for the production of large-size caps. The new design evolved at the Central Research Institute of Technology and Machine-Building needs very little factory-made equipment for its realization. The billet, a massive steel ring, is placed at the bottom of a concrete well upon a thin circular support. The well is closed tight with a heavy lid, and the blank is rotated at a speed up to five thousand revolutions per minute. On a special screen the billet can be seen stretching under the action of centrifugal force and in a few seconds is transformed into a finished part. The major difficulty that had to be overcome when evolving the new method was the whip of the billet during its deformation. This whip, which could wreck the shaft of the installation, seemed impossible to cure. There are very many serious reasons why such great pains are taken to balance fast-rotating parts properly. In the foregoing installation, the high speed of rotation is inevitably accompanied by a loss of balance, for the shape of a part is changed. Nevertheless from a series of ingenious experiments an original device was designed which ruled out any loss of balance regardless of the billet deformation. The underlying principle was to make the shaft float to its most stable position. The shaft is connected to the fixed components of the device by means of flexible links and universal couplings. As rotation begins, the shaft moves to the position of the principal axis of inertia of the ring, thus making impossible any loss of balance. The

shaft displacement in no way affects the remainder of the installation.

The above method has a large advantage over existing technology. Normally annular ingots are swaged on heavy presses with the aid of cumbersome accessories. Under these circumstances, a great part of the force developed by the press is spent not for deformation, but on overcoming the frictional resistance between the appliance and the part. This method is costly, unproductive and inconvenient.

The rotation method, on its part, practically instantaneously stretches a blank with a diameter of 300 mm into a disc with a diameter approximately twice as large. The speed in this case should be about 15,000 revolutions per minute.

As the new method does not place a limit on the blank size, it is possible to manufacture caps for electrogenerators which may produce power far in excess of 1,000,000 kilowatts.

When a large-size part is made, a new problem arises—how to heat-treat it? Some time ago, a problem of this kind arose at the Leningrad Metal-Working Plant. Cyclopean hydroturbine rotors manufactured for the Krasnoyarsk hydropower station and some other power giants of Siberia could not be heat-treated in conventional furnaces. It was suggested that they be cut into sections as it would be too expensive to build a unique mountain of a furnace and a new production shop to house it.

The problem was solved by building an unusual underground furnace in the existing shop. Imagine a round well four metres deep and more than eight metres wide. In the centre at the bottom is an opening for the supply of a gas-air mixture heated to the required temperature. In the walls of the furnace are three tiers of nozzles, these also supply the gas-air mixture and water

sprays. Nearby is a small booth, containing a multitude of instruments used to maintain the required heat treatment conditions.

A huge travelling crane carries the 300-ton rotor to the furnace and softly lowers it upon supports. Attached to the rotor are thermocouples which register the minutest temperature deviations at different points during the entire heat treatment process and send commands to actuating devices which regulate the supply and removal of heat.

The most notable feature of the underground furnace is that the entire heat treatment process, including heating and cooling, is done right on the spot, so there is no need to transport heavy parts from one place to another.

The process of cooling large welded units and castings is itself a complete science. The final structure of the metal and its strength depend on the rate of cooling. In addition, the castings, because of their mass, do not cool uniformly. This results in internal stresses. Hasty or poorly controlled cooling may fracture an almost finished part. This is why many months are taken to gradually cool such massive and expensive items as the beds of huge rolling mills, presses, turbine and pump housings.

Theoretically, it is possible to speed up substantially the cooling process. To achieve this, one has to calculate, on the basis of the laws of heat transfer, physical metallurgy and strength of materials, what the temperature should be at any given moment and point in a casting and the value of the resulting stresses. Then, the flow of cooling fluid is continually regulated to ensure that the cooling proceeds strictly in accordance with the planned requirements.

To translate all this into reality is extremely difficult, as a whole team of workers would be required

to regulate the cooling of each individual casting; and even the slightest error could lead to irreparable damage.

Such complicated problems are generally solved by using fast-response computers. At first, the optimum cooling procedure is calculated. This forms the basis of a programme which is fed into a computer. For the cooling information to be fed to the computer, hundreds of thermocouples are installed in the casting, thus making a feedback between the casting and the computer. Every few minutes the computer compares the information with the programme and, when necessary, signals actuating devices to either stop or step up the flow of cooling fluid at the required specific points of the casting. This method makes it possible to sharply accelerate the cooling process, as the present-day computers rule out any damage inflicted by uneven cooling upon a casting.

We have dealt with difficulties involved in the pressure forming and heat treatment of large-size units and parts. To this can be added the problems connected with transportation of items too big or too heavy to be transported by rail, their dimensional inspection and flaw detection, their assembly under field conditions, etc.

Engineers often face problems that seem unsurmountable, yet they are eventually solved. Having solved a problem the engineers improve the designs and afterwards continue the process of evolving still more impressive mechanical giants.

4. Electric "Sphynxes" Break Traditions

Experts consider that electric motors and generators had assumed their final structural forms nearly one hundred years ago and have not changed much ever since. Like stone sphynxes, these motors from the acme of their perfection view condescendingly on the frequent changes in the designs of other types of machines, but themselves remain unchanged.

This, however, is not quite so. In recent years, inventors have acquired patents for a great number of electric machines of the most exotic shapes and characters. Some of these machines are capable of developing speeds of many hundred thousand revolutions per minute, others move at a snail's pace. There have appeared motors consisting of two rings and three balls, and generators without a single moving part producing, apart from electricity, nitrogenous fertilizers. Nowadays, electrical machines are developing most rapidly in all fields of engineering.

MAGNETOHYDRODYNAMIC AC GENERATOR

Pulsating gas stream instead of inverters

If the question were asked about the source of every kilowatt-hour of electrical energy produced by all the

Electromotor moving at a snail's pace, invented by scientists at the Moscow Power Engineering Institute

power stations in the world, the answer in most cases would be: "A steam boiler generator". Does this mean that steam serves the purpose best, or that thermal power stations are not subject to sharp criticism?

The answer is in the negative, for the efficiency of such power stations approximates at best to only 40 per cent. Roughly speaking, out of 500 million tons of fuel consumed annually by the Soviet electric power stations more than 300 million tons are the figurative penalty paid for the imperfection of the steam producing plants. Fuel virtually flies from the chimney together with smoke and gases heating the atmosphere, is wasted because of incomplete combustion, high temperature of the cooling water which is disposed of, etc.

No matter how hard we try to improve a steam plant, its efficiency remains relatively low. The fact is that according to the laws of thermodynamics the efficiency of a steam plant depends on the difference between the maximum and minimum temperature cycles. The greater the difference, the higher the efficiency. The lowest temperature cannot be reduced any further, the limit being set by the temperature of the cooling water or air, so it is only the upper limit that can be raised. 600°C is the limit reached so far.

Undoubtedly, in due course, this limit will be surpassed, but the progress is becoming increasingly difficult. Neither because of high temperatures alone, nor because of the high pressures acting upon the steam turbine in operation, but because of a combination of these factors which cannot be withstood even by highly alloyed steel. As an example, for a 300 thousand kilowatt plant, Kharkov engineers have developed a turbine that has a terminal blade reaching a record length of 950 mm. With the rotor running, the centrifugal force acting on this blade exceeds 100 tons!

Further increase in temperature and pressure calls for the creation of new materials. This path, however, is long and thorny.

To use a simile, it is possible to liken the heat engineer to an agriculturist who tills once fertile but now with the years exhausted soil. In such periods of the history of technology, scientists and engineers continue their painstaking efforts to improve whatever is already available and simultaneously search new resources.

A new rapidly growing science, magnetohydrodynamics, is such a virgin land. Inventions in this field have paved the way for a drastic increase in the total efficiency of electric power stations.

Magnetohydrodynamics (MHD) is a combination of two sciences: electrodynamics and hydrodynamics. Electrodynamics is concerned with electric and magnetic phenomena, while hydrodynamics deals with all kinds of fluid motion. As soon as a fluid behaves like a conductor, it becomes the subject of both sciences. Magnetohydrodynamics is the study of the interaction of magnetic fields with electrically conducting fluids and gases. Gases become conductive when heated. In ordinary air heated up to 2500°K and over, the molecules collide with such a force that they disintegrate into atoms. At 4000°K, electrons leave atoms, the air becomes ionized and acquires the properties of a conductor. From that moment on, it may be influenced by magnetic fields.

The scope of scientific and practical applications of magnetohydrodynamics is unusually wide. Until recently it was only in the service of astro- and geophysics. This helped the development of the terrestrial magnetism theory and explained such cosmic phenomena as sunspots, magnetic stars, the solar corona, magnetic storms and aurorae.

At present, magnetohydrodynamics opens up new vistas in technology. Recently, a magnetohydrodynamic electric generator was invented. Basically, it only differs from a conventional generator in that the function of the armature winding is now performed by a stream of dissociated electrically conductive fluid or ionized gas.

Fuel (mineral coal, oil, gas or nuclear fuel) and pressurized air are fed to the combustion chamber or reactor of an MHD-generator. In the combustion chamber, this air is heated to 3000°K and becomes ionized. Then, the ionized stream of air passes thrcugh the generator magnetic field thus inducing direct current in its operating circuit.

Thus, chemical or atomic energy is directly converted into electricity with an efficiency of 60 per cent, this is one and a half times more than at most modern power stations.

Here, the inventors might as well stop, leaving all the remaining problems involved in the practical use of the invention to operating engineers. However, we have already mentioned, the MHD-generator produces direct current, while consumers must be provided with alternating power current. This requires rather expensive special inverters.

However curious this may seem, conventional generators work just the other way round: they generate alternating current which must be rectified to produce direct current.

Is it possible for an MHD-generator to produce alternating current directly? At first glance this appears almost impossible as a uniform stream of gas flows at a constant speed between the turns of the fixed winding. Without sudden changes it is impossible to produce alternating current.

However, any invention is, after all, a way out of

such seemingly hopeless situation. In this case, the way out was found by V. Yakovlev, post-graduate of the Institute of Electrical Engineering of the Academy of Sciences of the Ukrainian Soviet Socialist Republic. He has concluded that the gas stream should be imparted electrical properties variable relative to its length, for example, variable conductance, then the generator would produce alternating current.

Thus again a MHD-generator (Inventor's Certificate No. 141,961), but the fuel in its combustion chamber does not burn continuously, this is the difference from a conventional generator. The uninterrupted process of combustion has changed into a machine-gun burst of flashes at a rate of 3000 "salvoes" per minute or 50 "rounds" per second (the "rate of fire" of the generator corresponds exactly to the alternating current frequency). The gas stream resembles an endless rope with knots made at regular intervals, the knots being regions of high and low conductance. Now, if direct current from an excitation source is passed through such a stream it will concentrate at the points of low resistance. The gas stream splits into separate current conductors swiftly rushing past the winding, forming a travelling magnetic field which is similar to that of the excitation system of a generator with a revolving rotor. It is precisely this field which induces alternating current in the stator fixed winding. The voltage and power of this alternating current can be easily adjusted by varying the intensity of the direct excitation current passing through the gas.

ELECTRICITY AND FERTILIZERS FROM A GAS STREAM

MHD-generator produces electricity and nitrogen compounds at the same time

... Once, Russian chemist K. Falberg forgot to wash his hands after working in his laboratory. As he ate his dinner, he noticed that bread tasted sweet. Back in the laboratory, Falberg analysed the contents of the vessel into which he poured unnecessary residue after experiments. This is how he discovered saccharin in 1876, a substance 500 times sweeter than sugar.

... German inventor Josef Heilmann spent almost all his life trying to create a machine that would straighten and smooth out cotton fibres. Experiments had devoured all his savings and yet he could not solve the problem. One day he casually glanced at his daughters combing their hair, and that is how the principle of operation of a combing machine was found.

... English engineer Samuel Brown saw a cobweb in his garden that suggested to him the idea of a suspension bridge; the idea of using sunlight to treat skin tuberculosis was suggested to the Danish Nobelist Niels Fansen by an ordinary water beetle basking in the sun.

Historians of science seem to be fond of such anecdotes and try to liven up their lectures with them infusing a romantic spirit into the lectures and dispelling their boredom. Lest the students feel too romantic about it, the lecturer promptly adds that fortuitous and unexpected discoveries in science were only typical during its infancy. Alas! Such discoveries cannot be made today. Fortunately, despite what the scholarly pedants think, chance may help scientists even today. Quite recently, for example, Karl Ziegler, head of the Coal Derivatives Research Institute of West Germany, and Giuglio Natta, professor at the Milan Institute of Technology, received Nobel Prizes for the synthesis of stereo-regular synthetic rubber. Of course, that discovery was the result of intensive research, but the basic idea was prompted by an improperly cleaned chemical

apparatus containing traces of nickel that had led the scientists to the discovery of the new catalyst.

The invention described below was also made by chance. On sunny summer morning, Nathan Levin, a young engineer at the Moscow Nitrogen Institute, was on his way to work. The weather was fine, he had a few spare minutes, and so he stopped at a newspaper kiosk. His attention was attracted by an article by Professor A. Sheindlin, which described the operating principle of the MHD-generator, a device producing electricity directly from a stream of hot gases. Levin had never heard about this before and, as a matter of fact, could hardly have, for he was a chemist by education and had never read publications on power engineering. Besides, only a few days ago he had started working on the problem of combining atmospheric nitrogen which chemists the world over have been trying to solve for almost half a century. Perhaps, just because of this he was able to look at the problem from a totally different angle. He was amazed to discover that the processes of fixing nitrogen and producing electric energy by an MHD-generator were as like as two peas.

* * *

N. Levin read Prof. Sheindlin's article on 25th of June, 1961. Three days later he presented his idea to the professor. The inventor was backed by Academician M. Styrikovich, a Soviet authority on steam boilers, and by other scientists, physicists and power specialists, and so work on the invention started.

At that time, some ten years ago, the first Soviet electric MHD-generator had been developed at the Institute of High Temperatures by a group of scientists headed by Academician V. Kirillin and Corresponding Member of the USSR Academy of Sciences A. Sheind-

lin. This was a small, almost table-sized laboratory installation. Its power was hardly sufficient to deflect the pointers of highly sensitive instruments. Relative to the present-day industrial prototype, it was like comparing a toy car to a 40-ton dump truck, but it worked, produced current and thus proved the theoretical principles underlying its design. These principles are so simple that every school-boy knows them. An MHD-generator differs from an ordinary dynamo only in that the function of the copper armature winding in it is performed by a stream of dissociated electrically conducting fluid or ionized gas. When such a stream cuts the lines of a magnetic flux, electromotive force is induced in it. If collecting electrodes, connected through an external circuit, are placed round the stream, they will collect the induced current and the chemical energy of the fuel will be directly converted into electricity. Thus, we get rid of steam and the steam boiler, of turbines and other moving and rotating parts, and there are no worries about wear, metal fatigue, lubrication, etc. Servicing a power station becomes extremely simple and the whole process of producing electricity can be easily automated. However, the most important thing is that the elevated temperatures (2500 to 2800°C) make it possible for the efficiency of power stations to be increased from the existing 40 to 50-55 per cent. On a national scale, each per cent means saving several million tons of coal and oil each year.

It is curious that the idea of an MHD-generator is, in fact, not new at all. It was put forward half a century ago. But only recently has it become possible to materialize this idea because of the extensive space, nuclear and missile research programmes from which information has been obtained about the properties and behaviour of gases at elevated temperatures, and new heat-resistant materials have come into use.

* * *

By the end of the last century, nitric acid, which is the basic component of numerous nitrogen compounds used in the manufacture of fertilizers, plastics and aniline dyes, was produced from sodium nitrate decomposed by means of sulfuric acid. Sodium nitrate had to be transported from as far as Chile, this seriously hampered the development of chemical industry. That is why chemists attached much importance to the problem of fixation of atmospheric nitrogen. In 1901, Norwegian scientists Birkeland and Eyde succeeded in fixing atmospheric nitrogen in an electric arc. This method, however, was not extensively applied because of the extremely high consumption of electrical energy, more than 10 thousand kW-h per ton of fixed nitrogen. A more effective method was proposed in 1913 by German chemists Haber and Bosch, which is based on the catalytic synthesis of ammonia from atmospheric hydrogen and nitrogen. At present, this is the basic industrial method through which some 15 million tons of fixed nitrogen are put out annually all over the world. Effective as it is, the synthesis of ammonia has serious disadvantages; it calls for elevated pressures and temperatures, sophisticated and expensive equipment. Would it not be much simpler to fix nitrogen directly by combining it with oxygen? This idea is not new either, but because it involves enormous power consumption it could not this far be materialized on an industrial scale.

* * *

Six years after its appearance, the table-mounted MHD-generator model has grown into a powerful experimental plant Y-02 installed at one of Moscow

power stations. The work on the plant was sponsored by the Ministry of Power and Electrification, USSR, and supervised by the Institute of High Temperatures of the USSR Academy of Sciences.

A stream of hot gases rushing at a jet fighter's speed washes metal electrodes and gives them 2000 kW of energy for every cubic metre of the generator's working volume. The air, however, heated to such elevated temperatures always forms nitrogen oxides whether we like it or not. Thus, the MHD-generator, apart from producing electricity, is a natural chemical apparatus in which the requisite reactions take place. To prevent nitrogen oxides from disintegration, they must be rapidly "quenched", i.e., instantaneously cooled at a rate of 20 thousand degrees per second. This can be easily attained in an MHD-generator by passing the obtained oxides through an expanding nozzle. To intensify "quenching", water can be injected through atomizers into the incandescent stream of hot gases. It only remains to trap the products of the reaction to obtain nitrogenous fertilizers. This can be done by passing the gas stream through a tower filled with dolomite which promotes the formation of nitrates and nitrites of magnesium and calcium. Thus, it is only necessary to install one extra element, the tower, to make a chemical plant out of an MHD power station, but is it indeed an extra element? As we know, nitrogen oxides are extremely toxic. Mixing with automobile exhaust gases, they produce heavy smog which eats up nylon stockings and corrodes steel. Smog causes tarnishing, cracking, weakening and decoloration of all kinds of materials, kills vegetation and ruins health. Therefore the nitrogen oxides have to be trapped by all means. Then, why not also use them to produce fertilizers?

Power engineers and chemists benefit equally from all stages of production of energy and chemicals, from

high-temperature heating of gases and their instantaneous cooling, which substantially increases the efficiency of the device and the yield of nitrogen compounds, to the trapping of by-products. This is why such a combination of chemistry and power engineering is both desirable and necessary. What is more, it is highly profitable, because the production of nitrogen compounds does not call for additional fuel consumption. The cost of chemicals produced by an MHD-generator is, according to some estimates, almost equal to that of the electric energy produced by the same generator, so the overall gain may also increase twofold. The economic aspect of this problem is of paramount importance as the stumbling block in the progress of MHD-power engineering and direct oxidation of nitrogen has always been their relatively high cost. The new invention of Soviet scientists will substantially reduce the required capital investments and cheapen both processes.

Of course, this view of the situation is too simple. A great number of extremely complex physical and chemical phenomena attending the operation of an MHD-generator are still to be studied. So research continues. The experimental installation we have described has two channels, big and small. While the big channel is used to study the interaction of plasma with the magnetic field set up in both channels and the generation of high-power energy, the small one is used to examine the electric discharge characteristics, test materials and analyse the composition of plasma. Here, too, the chemical and power engineering studies go hand in hand.

Scientists working on this problem can hardly tell just what they specialize in. The inventors of the new method include power physicists and chemists. The physicists are Alexander Sheindlin, Corresponding

Member of the USSR Academy of Sciences and Head of the Institute of High Temperatures, and Vladlen Prokudin, a research worker of the same Institute. The chemists are Nathan Levin, Deputy Chief of the Scientific and Technological Department of the State Institute of Nitrogen Industry, Adam Rozlovsky, Doctor of Chemical Sciences, and others.

A tiny streamlet of the electric current produced by the experimental MHD-generator already flows into the country's power system. Soon it will grow into a mighty torrent of chemical and electric energy, with every million kilowatts yielding several hundred thousand tons of nitrogen compounds a year.

MULTIMILLION-VOLT GENERATOR

A new method of directly converting heat into electricity has been invented by Moscow scientists

On that memorable day, Dmitry Tambovtsev, a junior research worker at the Institute of Crystallography of the USSR Academy of Sciences, was unusually nervous, because he was to demonstrate an invention. Just before the Academic Council was to meet, he decided to check the apparatus once again. No current, as expected! He barely had time to replace the crystal when the meeting of the Council started. This time, everything went just right. As soon as he brought a translucent disc coated with finest silver powder close to the heat source, an ordinary electrical reflector, the room was illuminated with a series of dazzling flashes. The audience burst into applause and requested that the experiment be repeated.

That was the first demonstration of a new method of directly converting heat into electricity invented by Doctor of Physics and Mathematics I. Zholudev, Head

of the Laboratory of Electric Properties of Crystals at the Institute of Crystallography of the USSR Academy of Sciences and Candidate of Physics and Mathematics V. Yurin (Inventor's Certificate No. 154,625).

The device for effecting this method is as simple as can be: it comprises a diamond-shaped plate made of an organic substance, triglycine sulfate, which looks like plexiglass, and two electrodes collecting current from its surface. Nothing more. The structural simplicity of the device, however, is the result of profound physical research.

As long ago as in the thirties of the past century, Faraday had already noticed that dielectrics such as mica, porcelain, ebonite, quartz and other substances possessing very low electric conduction, are capable of polarization, i.e., of acquiring such a state when the centres of gravity of positive and negative electric charges forming the dielectric are mutually displaced. A piece of a polarized dielectric resembles a conventional capacitor with one plate charged positively, and the other, negatively. However, for a polarized dielectric to remain polarized, it should constantly be influenced by an external electric field. This, of course, is not very convenient.

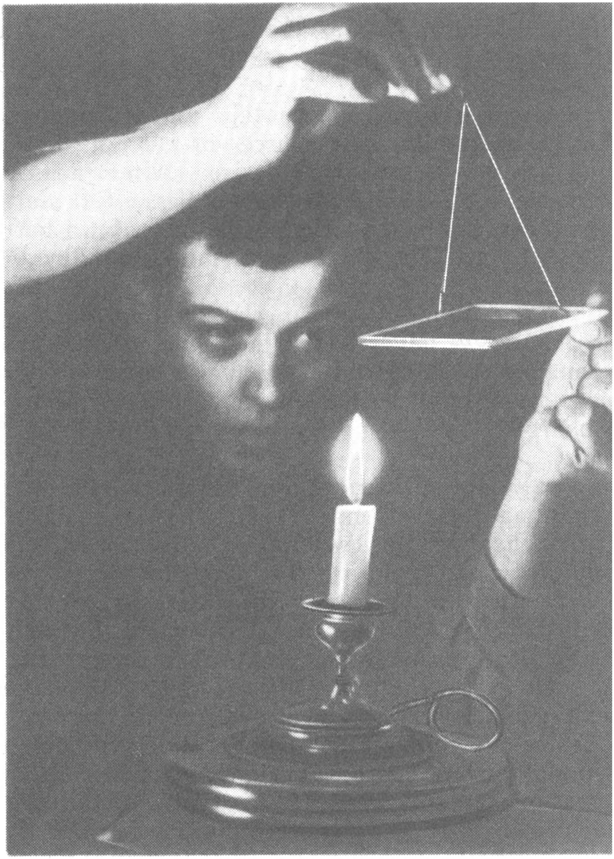
Luckily, in 1918, D. Anders, an American physicist, found that certain substances, for example, Seignette salt, displayed what can be defined as "voluntary" polarization, i.e., spontaneous dielectric polarization which does not call for any external electric fields. Such substances were termed ferroelectrics. First comprehensive studies of their properties were conducted in the thirties at the Leningrad Institute of Physics and Technology by Academician I. Kurchatov. Many new ferroelectrics have been discovered since then. Physicists have thoroughly studied their properties and have found a wide range of applications for them. In recent

years, electronic development has rekindled the physicists' interest in ferroelectrics.

While experimenting on crystals of triglycine sulfate, an organic salt of sulfuric acid, irradiated with gamma-quanta, Professor I. Zholudev and Candidate of Physics and Mathematics V. Yurin concluded that a thin plate of this translucent substance is capable of directly generating high-voltage current without any converters and transformers.

To understand this phenomenon more fully, let us consider an ordinary capacitor consisting of two oppositely charged plates with a dielectric separator between them. Join wires to the plates, close the circuit by connecting these wires to an external load, periodically bring the plates together and apart, and you have the simplest generator producing electric energy.

Indeed, with the constant charge, the voltage across the plates is directly proportional to the capacitance of the capacitor, while the capacitance is inversely proportional to the distance between the plates. When the plates are drawn apart, work is expended to defeat the electric field forces attracting the oppositely charged plates to each other, thus decreasing the capacitance of the capacitor. However, the charge across the plates remains constant, which means that the voltage increases. This, in turn, means that the amount of electric energy stored in the capacitor increases. Of course, drawing the plates together and apart is not very convenient as a complicated mechanical system is required for this purpose, a special motor. Is it possible to do without it? If we study the formula for calculating the capacitance of a capacitor more closely, we shall see that the capacitance may be varied not only by moving the plates, but also at the expense of the dielectric constant of the separator. Since the latter value changes with temperature, by alternately heating and cool-



Electric generator made as a single piece at the Institute of Crystallography of the USSR Academy of Sciences

ing the capacitor we can vary its capacitance and produce electricity as was the case when the plates were moved. This is exactly what the Americans have done.

Numerous articles in scientific journals noted the extensive use of the new sources of current. Yet, the sailing was not as smooth as desired. After each operating cycle, the capacitor discharges to the full and has to be recharged from an electric battery. But a battery is a very unreliable, cumbersome and short-lived device.

I. Zholudev and V. Yurin chose a totally different approach. As we have already mentioned, they replaced the capacitor by a crystal of triglycine sulfate, a ferroelectric, capable of permanently maintaining its polarized charged state without any external electrical influences.

To raise the efficiency, they irradiated the crystal with gamma-quanta from the radioactive isotope cobalt-60. Upon heating, positive and negative charges move apart, the capacitance of the ferroelectric capacitor drops, and the voltage across its plates increases. If an external electric load is connected during the interval between heating and cooling, an electrical breakdown occurs. However, the initial charge of the ferroelectric, its emergency reserve, so to speak, remains intact, and the device is again ready for operation without any additional current sources. Tests indicate that although its efficiency is only 2 to 2.5 per cent and the specific capacity equals 10 to 15 watts per kilogram, the device develops a voltage as high as 10 thousand volts. This voltage is used with the greatest advantage to feed electric filters and some other devices. Even this is not the limit. Other substances may yield still better results. It is interesting that voltage depends not on the area of the plate, but on its thickness. If we arrange scores

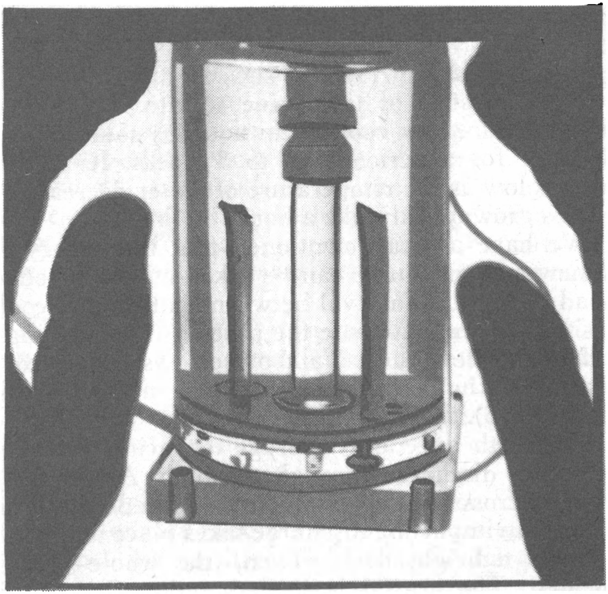
of such plates in series, we can obtain voltage soaring to millions of volts!

It is not difficult to make such an apparatus. All we need are crystals of tryglycine sulfate. These can be easily produced by cooling an aqueous solution of this substance for a period of 2 to 3 weeks. Its solubility becomes low as the temperature of water decreases, and crystals grow quickly like a house on fire.

We have already mentioned that the energy from the new current source can be taken off by introducing a load during the interval between heating and cooling. To simplify and automate the process of connecting this load to the device, D. Tambovtsev has suggested that a flash bulb be used as the load (Inventor's Certificate No. 155,873). It is connected to the ferroelectric in parallel with an energy storage capacitor preventing premature discharge through the bulb. As soon as the voltage across the capacitor plates exceeds the ignition voltage, an impulsing discharge takes place and the bulb produces a bright flash. Then, the whole process is repeated. The crystal is heated and cooled within a narrow temperature range: from 25 to 50°C.

The efficiency of the new device, which is only 2.5 per cent, is rather low, but in places where this is of no particular significance, where the thermal energy is cheap, while heating and cooling are effected automatically, the novel current source will be of great utility. If we arrange a number of such cells provided with flash bulbs on an artificial satellite, they will make a real space beacon, for the satellite, being permanently in a spinning motion, alternately exposes its sides to the scorching rays of the sun and the deadly cold of outer space. Conventional silicon solar cells fail to develop high voltages, whereas increasing the voltage by means of converters is extremely difficult.

If we arrange crystals over the inner surface of a



An unusual electrological motor, invented by Byelorussian scientists, represents a rod immersed in non-conducting liquid and rotated by electric field. The motor operates both on alternating and direct current, with any voltage up to 30 kV, can change its speed from 10 to 1000 rpm. It has neither magnets, nor brushes, nor bearings

hollow sealed sphere, let sunbeams pass into the sphere through glass lenses, and moor it, it will make a perfect sea buoy: heaving with the swell, the sphere will alternately expose different crystals to the sunlight, thus ensuring the required change of temperature.

And, finally, the flash bulb combined with a ferroelectric crystal will be of great use to photographers.

In this case, however, a complementary source of heat, at least a candle, should be provided.

The new method of directly converting heat into electricity has a long way to go before it can be extensively applied, and there is still much to be done to improve the efficiency, power and durability of the device.

PISTON-OPERATED GENERATOR

Electric machine with a reciprocating rotor

At diesel-electric power plants, the reciprocating motion of the diesel engine pistons is translated into the rotary motion of the engine shaft by a crank gear.

On the whole, the diesel plant is rather large; it occupies much space in the engine room, so you can always tell a diesel-electric power station from a steam or gas power station by the size of the engine room.

The desire to create a compact engine for power stations using internal combustion prime movers prompted Soviet inventors G. Areshian, D. Avetisian, L. Meisel and A. Ter-Mkrtchian to develop an interesting and radically new machine (Inventor's Certificate No. 133,517).

They have decided to eliminate the heavy crank gear operating under severe conditions because of the sharply fluctuating loads and coupled the generator directly to the piston rod of the diesel engine.

For this purpose, they had to change the design of the generator and give its rotor reciprocating motion, not rotary (this brings us back to early generators of a hundred years ago). They arranged operating solenoid coils on the stator and replaced the rotor by movable cores fitted onto the piston rods.

Thus, a very compact and simple unit was obtained.

As the combustion gases expand, the pistons push the ferromagnetic cores inside the solenoids (a power stroke). Now, what forces the cores back from the solenoid during the idle stroke which follows? It is compressed air in the air buffers positioned between the working cylinders and the generators.

As the load on the generator varies, the operator accordingly adjusts the supply of fuel to the working cylinder and the initial air pressure in the buffers.

MIRROR SWITCH

Electric motors without sparking contacts

How many applications could you find for the small mirror carried so carefully in a lady's handbag?

The Soviet inventor A. Dubensky, Cand. Sc. (Tech.), has found a totally new application for the mirror (Inventor's Certificate No. 129,716).

He fixed the mirror to the end of a DC motor shaft and directed a beam of light from an electric bulb to it. The beam reflected by the mirror started rotating with the same angular speed as the rotor of the motor.

According to the invention, sections of the working winding are arranged in the slots of the stator, each section being provided with a photoresistor through which it is connected to the electrical circuit.

As the rotor rotates, the light beam reflected by the mirror hops from one photoresistor to another "disrupting" them one by one so that the winding sections are switched over one after another, and the motor runs at a steady speed.

Thus, the mirror has replaced a mechanical switching device, the commutator, and opened the way for the creation of a DC motor capable of operating at very high voltage without sparking.

By applying the same principle to a dynamo, one can evidently devise a generator to produce high-tension direct current. Incidentally, an American firm has developed a rheostat using a light beam, which can work practically eternally as it has not a single wearing or rubbing part. The gap between the contact and the variable resistor is filled with a semiconducting material. As a light beam scans across the semiconductor, the latter becomes conductive and closes the circuit.

ELECTROMOTOR FROM BALL BEARINGS

Thermal strain drives the motor

Are windings, a stator frame, a collector and the like indispensable in every electromotor? Not in the motor invented by Novosibirsk engineers V. Kosyrev, V. Rabko and N. Velman. Their motor (Inventor's Certificate No. 155,216) seems to be the simplest one ever made. What is more, it can operate on both direct and alternating current. The motor is nothing but an ordinary antifriction bearing with only three balls. Pressed into the inner race, which is the rotor, is a steel disc, which is the core, and direct or alternating current is applied to this core through a miniature brush. The other contact is connected to the fixed outer race, which is the stator. To start the motor, it is enough to energize it with a current as low as 5 to 10 amperes and give it a slight push. Passing through the balls, the current unevenly heats the races. This results in a circumferentially developing thermal strain which maintains a constant rotational speed. Of course, such a motor cannot develop much power and its efficiency is rather low, but if you are after simplicity of design, it is beyond competition.

5. Jet Engine Down from Heaven

In one of the preceding chapters, we have already noted that every field of science, including chemistry, aims not only at producing useful things, but also at finding new applications for those that have long been known. Indeed, this is the case with most inventions in chemistry: they find a new, sometimes quite unexpected application for a well-known substance.

This actually happened to jet engines used in missiles and in aircraft. The jet of hot gases issuing from a nozzle with a deafening roar turned out to be a most convenient and versatile means of solving many technological problems.

Jet mills, drilling rigs, quarry aerators, granite cutters, fertilizer and insecticide sprayers, fire extinguishers, sea water distillers, snow blowers, road dryers and a multitude of other machines are powered by discarded jet engines.

BY ROCKET FROM THE DEPTHS OF THE EARTH

Jet engine helps to move drilling equipment up and down the well

People knowing, but little, about oil extraction picture the process like this. A well is drilled in an oil field and pipes are lowered into it. Then, as the formation pressure becomes sufficiently high, oil starts gushing out; if the pressure is not high enough, it is pumped out. That is almost all about it.

To put it mildly, this is not quite so in practice. Oilmen have a long way to go from drilling a well to filling storage tanks with oil. Once a well has been drilled, drill operators make way for geophysicists. These probe the well with a number of instruments in order to determine the permeability, electrical resistance and other parameters of the rock. Then, from the careful analysis of all the obtained data they know exactly how deep the oil-bearing beds lie and, accordingly, lower torpedoes or perforators loaded with an explosive charge to a prescribed depth and initiate the charge. Splinters and hot gases pierce the pipe, and oil rushes through the holes and fills up the well. This is when oilmen may actually start extracting oil.

While oil prospecting, drilling and pumping have been radically improved in recent years, the methods of delivering instruments and explosives down the well are still primitive. Sophisticated equipment stuffed with electronic gadgetry and radioactive tracers is still moved up and down oil wells the world over just like buckets in village wells, the only difference being steel cables used instead of ropes. However, the depth of a village water well is a few tens of metres at the most, but an average oil well is 4 to 5 kilometres deep. This is why the outwardly simple job of extracting oil is actually a very complicated and costly business.

First of all, a cumbersome hoist and a sizable coil of cable have to be delivered through or to virtually impassable swamps or impenetrable forests. The cable must be made of high-tensile steel, or it will break

under its own weight, to say nothing of the weight of equipment it has to carry, especially if we consider that in the course of operation, it loses its tensile strength, so the service life of a cable is rather limited. At the same time, oil wells become deeper and deeper. As a result, the cable becomes heavier and is subjected to higher temperatures. Thus, it has to be made more heat-resistant. Still, drillers are faced with an increasing number of failures due to breaks in the cable's centre conductor which is highly sensitive to excessive loads. As equipment is lowered to a considerable depth, the weight of the centre conductor practically does not count because of the tremendous weight of the cable itself. As a result, the conductor slackens and kinks are formed on the cable, this being a problem to engineers. Because of the kinks, they do not know exactly where the explosive charge is positioned, and quite often the pipe is perforated in the wrong place, for instance, at the level of the water-bearing layer instead of the oil-bearing bed, and the well is flooded. A break of the cable carrying an instrument or apparatus in a deep well may cause even more trouble. It takes much time and effort to get things straight, and special smaller tubes with gripping devices have to be repeatedly hauled up and down the well. This is arduous toil, and more often than not it proves ineffective. To make things worse, many wells are currently drilled obliquely with some sections being almost horizontal. It is absolutely impossible to bring equipment down such a well by means of cables.

In short, cables have become a burden and source of accidents for oilmen. Why not get rid of them altogether? This is what has been done by a group of inventors at the Ramenskoe Branch of the All-Union Geophysical Scientific Research Institute, comprising Norair Grigorian, Head of the Ramenskoe Branch, Lev

Friedlander, chief project designer, and Nikolai Guschin, leading designer (Inventor's Certificates Nos. 187,700 and 187,701). Their solution was so self-evident that it seems absurd that no one had thought of it before. This after all is the feeling one gets after an invention has been made, when a commonly used but ineffective technique is blown to pieces by a daring novel concept.

Let us see if we really need a cable to send some piece of equipment down an oil well. If we attach a sufficiently heavy weight to the piece of equipment, a torpedo or a perforator with an explosive charge, and let it go down the well, it will be immersed in the surrounding flushing fluid. We need not worry about the acceleration: the acceleration of the apparatus will be accompanied by a growing resistance of the fluid which will serve as a natural damper.

Lowering the apparatus or explosive charge into the well is only a part of the problem, it must be actuated exactly at a preset depth. This is why a cable also has to perform the function of a meter and its centre conductor is supposed to transmit a trigger pulse. Both functions can be effectively performed by a simple computing and initiating device, especially in view of the fact that the cable often fails to cope with these tasks due to frequent breaks of the centre conductor and inevitable kinks. As the inventors see it, such a device would easily orientate itself in the well by counting the couplings joining individual casing pipes to one another to form the case string. Abutting pipes are always separated by a gap, otherwise it would be impossible to properly secure them together by means of taper threads. A tappet roller will enter into each gap and send one pulse after another to a bicycle-type counter. The counter is provided with three discs with digits from "0" to "9", but it differs from a con-

ventional bicycle counter in that one can preset any indication from "0" to "999". This is what is actually done before the cable is lowered into the well, when one knows exactly at which gap the apparatus should operate. As the apparatus goes down the well, the meter counts down and, on reaching zero, closes an electric circuit or actuates the spring of a mechanical triggering device.

It must be said that the tappet roller is not the only solution. Couplings may be also counted by means of a magnetic detector comprising a coil with magnets which generates electric pulses in response to a variation in the magnetic resistance of the pipes. Near each coupling, the magnetic resistance grows and the counter ticks off another digit. If we mark the couplings with radioactive or magnetic substances, other instruments may be used as well. The initiating device may be also provided with an ordinary curvimeter normally used for measuring distances on maps and charts, but somewhat bigger in size. In the curvimeter, the rotation of the roller sliding on the inner surface of the pipe, as the apparatus goes down, is transmitted through a gearing to a meter, and the latter reads the depth directly in metres. Devices using hydrostatic pressure transducers are equally reliable. In a word, there are numerous methods of calculating the depth of a well, each being far more reliable than the former method of measuring the length of a cable.

Finally, the cable must haul up the equipment or whatever is left of it after the explosion. After the ballast has been dropped, this operation can be performed far more effectively by an ordinary float which may be a specially designed cavity, hollow or filled with foam plastic, inside an apparatus. However, from obliquely drilled wells or from wells with almost horizontal sections, the equipment will either not come

to the surface at all or will do so too slowly. In this case, it is wise to use jet, steam-gas or compressed air engines. Such engines are mounted, for example, on sea torpedoes, propelling them at very high speeds.

...Thrown into the well, down through the turbid flushing solution goes an explosive charge with a ballast, a meter and a small solid-propellant rocket. A sonic detector on the surface continuously controls the descent of the equipment, picking up the rattle of the tappet roller against the pipe couplings. We hear a distant blast. The charge has gone off perforating the pipe, and oil rushes from the bed into the well. The ballast drops and goes to the bottom of the well. At the same time, an electric pulse arrives at the delay igniter of the rocket. In a few seconds, the solid propellant blazes up. Hot gases rush through the nozzle and the reactive force pushes the apparatus up to the mouth of the well. Spring latches snap, the buffer claps, and the apparatus is trapped. Once recharged, it is ready to go down the well again.

The rocket propels the apparatus up at a speed of 10 to more than 15 kilometres per hour, while a cable cannot develop a speed exceeding 5 to 6 kilometres per hour, otherwise it will break down. It is apparent that the new method saves a lot of time in very deep wells.

The tractive effort of the rocket must defeat the forces of gravity and the resistance of the fluid as the apparatus moves at a prescribed speed. The perforator of the PK-105 type, for example, weighs 34 kg. With the metering and initiating device and the reaction chamber, the total weight of the rocket amounts to some 50 kg, and in water, 35 to 40 kg. If we allow 10 to 15 kg for the water resistance, the tractive force of the rocket will amount only to 50 kg. Since the resistance of the fluid grows with speed, it will act, as it does

during the descent, as a perfect speed regulator preventing the rocket from attaining dangerous speeds. To ensure continuous operation of the engine throughout the ascent, the propellant charge in the reaction chamber is shielded on all sides except one so that it can burn slowly like a Bickford fuse. Estimates show that lifting a 50-kilogram load from a depth of 5000 metres will only require half a kilogram of solid propellant.

Having considered the above inventions, the Ministry of Geology of the USSR found the new method capable of delivering down an oil well, under the action of gravity, the initiating and explosive equipment. Lifting the initiating and explosive equipment from the well by means of a built-in jet engine is also possible. The idea of a perforator or torpedo with a metering and initiating device for counting pipe couplings in the casing string to locate the place of explosion is also sound. The suggestion to effect control by means of a sonic detector installed on the surface to pick up the clicks produced by a tappet roller against the pipe couplings, as well as the sound of the blast, is also valuable.

The inventions put forward by the geophysicists of Ramenskoe will enable the national economy to save enormously. Now let us see what these savings will amount to.

An average oil well is 4000 metres deep. The per meter cost of hauling up and down the equipment is 1.2 copecks. Therefore the cost of lowering and raising one piece of equipment will be some 50 roubles. To complete one drilling operation, the equipment has to be moved up and down thirty times. This will amount to 1500 roubles. The new method makes it possible to save two thirds of this sum, i.e., 1000 roubles per well. As some 6000 oil wells both prospecting and operating

are drilled annually in the Soviet Union, this represents an enormous saving.

So far we have only dealt with oil wells. But there are also water-supply, gas and other wells in which the invention can be used with equal advantage. We also have to take into account losses due to frequent breaks of the cable resulting in prolonged standstills. Summing up all these factors, the estimated annual savings due to the introduction of the new method may run into millions of roubles.

JET MILL

Jet-engine flame grinds ore

Along with gigantic machines of power engineering, metallurgy, cement and construction industries, there toils a whole army of modest-looking machines. They are far less known than their big brothers they work for—blast furnaces, turbines and the like—but without these machines the whole industry would come to a standstill. A case in point is ball mills grinding each year about a billion tons of coal, iron ore, cement clinker, metallurgical slag and raw materials to produce various construction materials.

A ball mill is a huge welded drum filled with balls made of hard steel. When powerful electric motors set the drum into rotation, the balls roll with a deafening roar and crush coal, ore or slag into powder. In the process, the balls wear out at a rate of 2 kg per ton of ground material. It is easy to calculate that irretrievable losses of metal amount to millions of tons. And what about electric power? Here too, ball mills are prodigal spenders. We are right to criticize steam locomotives for their low efficiency, but we forget that the efficiency of ball mills is 100 times lower. Accord-

ing to power engineers' estimates, ball mills waste about one fifth of the total electric energy produced in the country, just by transforming it into heat.

B. Telnov, an experienced builder, felt that the utter imperfection of the existing technology could not be overcome by minor improvements and modifications. Instead, he suggested a radical solution.

Imagine two small jet engines with their nozzles facing each other. Roaring gushes of flame catch pieces of rock or ore sand and, carrying them at supersonic speed to where they meet, collide and disintegrate into minute particles. Disintegration is also facilitated by the elevated temperature which minimizes the strength of any material. In addition, instantaneous boiling of the water often contained in crystals produces micro-explosions which break them apart. All this substantially reduces the energy expended in destruction. At the same time, the material being disintegrated is also subjected to roasting.

If we want to obtain very fine powder, the material is passed through the jet mill once again. The powder is pulverized to dust. The size of each particle does not exceed tenths of a micron!

Such fine powder is a blessing for builders. When added to concrete, it imparts the latter exceptionally high strength.

A jet stream is not only capable of reducing every material to powder. It can also be used, for example, to obtain mineral wool, soft and fluffy as down. The starting material in this case may be dolomite, limestone or blast-furnace slag, which are premelted in a cupola. As soon as boiling material starts flowing from the furnace, the gas jet catches it up, divides into droplets and draws each droplet into long fine fibres slowly descending like snow-flakes onto a passing conveyer. Recently, this was done by using steam, as is still the

case with many plants even today. Calculations and tests indicate that Telnov's installations are 50 times cheaper than those using steam-generating boilers, for they consume 10 to 12 times less fuel and produce mineral wool of a far superior quality.

It is clear to see how much the introduction of the new method holds in store for the national economy with construction going on at an ever increasing rate! Even now the production of mineral wool and felt in the Soviet Union amounts to millions of cubic metres and is steadily rising.

The jet installations invented by Telnov will be also of great use in the production of metal powders. Once a stream of hot gases is blasted on molten metal flowing from a ladle, it is dispersed into tiny droplets which solidify in flight and turn into fine powder.

We have already known that discarded jet engines dig ditches, dry corn, spray fertilizers and herbicides. Telnov's inventions have made them applicable in power engineering, metallurgy, manufacturing of construction materials, and building industry.

JET ENGINE DRILLS EARTH

Jet drill invented by General M. Tsiferov breaks cutting records

Among the growing family of flame-throwing drills burning their way through the depths of the earth, the most original is the one invented by Major-General M. Tsiferov (Inventor's Certificate No. 79,119). This drill, provided with an autonomous gas producer, requires no mechanical linkage with surface equipment. In the course of operation, it is supported by the reactive force of the gas jet and is thus kept suspended, floating above the bottom of the well. As the engine is

running out of fuel, an automatic switch sharply intensifies the thrust, and the drill rockets up to the mouth of the well where it is trapped by a pneumatic catcher. Once recharged, the device can be sent back to the bottom of the well. Estimates show that one charge of fuel is sufficient for one hour of operation of the drill. During this period, the drill can penetrate some 100 metres of normal stratified rock.

The invention was patented more than 20 years ago, but only today has it become technically feasible to put it into practice.

JET ENGINE IN REVERSE

A new refrigerating machine invented by Soviet scientists and engineers revolutionizes many production processes in metallurgy, construction, mining, as well as in rubber and food industries

What is a refrigerator from the point of view of thermodynamics? Nothing more than an engine, only operating on the reverse cycle. To the conventional engine, we supply heat and obtain mechanical work; with a refrigerator, it is the other way round: we supply work to obtain cold. Reciprocating heat engines have been around many years, reciprocating refrigerating machines being their thermodynamic counterparts. Now gas-turbine engines have come into being. Thanks to their tremendous power and compactness, they have revolutionized aviation and some other fields of power engineering. Perhaps, their counterpart, a gas-turbine refrigerating machine, can revolutionize refrigerating engineering.

We shall now try to explain in a simple way the logical pattern which led a group of Soviet inventors, through elaborate and fundamental theoretical research,

to the creation of a radically new turbocooling unit that was given the abbreviated name TXM-300 (Inventor's Certificate No. 136,737). The group included Serghey Tumansky, Corresponding Member of the USSR Academy of Sciences, Moisei Dubinsky and Grigory Livshits, Doctors of Technical Sciences, Vladimir Martynovsky, Head of the Odessa Institute of Food and Refrigeration Industry, Candidates of Sciences Victor Zakharenko, Boris Lesun, Alexei Levshuk, and Engineer Valentin Lapshov.

The new refrigerating machine is just the opposite of a turbojet engine. An aircraft engineer will find a number of familiar elements in it: a multi-stage axial-flow air compressor, a gas turbine and an exit nozzle. But what about a combustion chamber? There is none at all. Instead, provision has been made for an electric motor, a reduction gear, a rotating turbocompressor shaft, also a few valves and two cylinders resembling oil drums. These are regenerators or, in other words, cold accumulators, each comprising a shell packed with corrugated aluminium foil strips.

Let us now see how the machine operates. The motor is switched on. The reduction gear brings its standard 1400 rpm to 21,200 rpm. The compressor and turbine wheel are set into rotation. The compressor sucks in the air from the system, then vents it out. The pressure in the system is reduced. One of the valves is opened and the warm atmospheric air is admitted to the turbine. The air rushes into the turbine because the space downstream of the turbine is evacuated. Having passed through the turbine, the air gives to it part of its energy. The air pressure drops to half an atmosphere. While expanding, the air is cooled down. From the turbine, the air enters the exit nozzle, then passes through the regenerator, cooling it by 30°C and also depositing moisture, and, finally, reaches the compres-

sor. There the air is compressed, heated to +110°C and released into the atmosphere. By alternately shutting off one or another regenerator, we cool them down to a low temperature and connect the refrigerating chamber to the machine. Theoretically, it takes four minutes for the machine to start operating in the rated duty but practically, due to various losses and disturbances, the process takes half an hour. In conventional refrigerating plants, this period lasts a few hours.

The operation of the TXM-300 under stabilized conditions is very simple and highly effective. Atmospheric air is admitted to the cold regenerator, leaves its moisture in it, is cooled down to —80°C and fed to the refrigerating chamber. The heat released by the articles being refrigerated, increases the air temperature by 30°C, this air goes to the turbine, expands, is cooled to —83°C, passes through the second regenerator charging it with cold and picking up the moisture it has previously left, then passes through the compressor, is compressed again, heated and released to the atmosphere. Every minute, the valves are alternately opened and closed, and the regenerators change over. With the total weight of two and a half tons and the power of the electromotor being 75 kW, the TXM-300 every second cools almost one cubic metre of air down to a temperature of —80°C. Unlike other refrigerating machines, the TXM-300 requires no cooling water, is transportable (it can be easily carried by a truck), has no complicated evaporator-and-condenser system, produces both hot and cold air, is cheap, easy in manufacture, contains no copper parts, and can be easily automated. It can be driven by any conventional motor. It is also very important that the new machine can operate without special coolants, ammonia or freon. This solves all the safety problems. Let alone the high cost of freon, it forms, if fire breaks out, poisonous

phosgene which is a chemical warfare agent. Ammonia is no better: it is toxic like chlorine which causes destruction and necrosis of tissue, depresses the nervous system, activates tuberculous process and eventually leads to deafness and asphyxia by causing spasma of the trachea. As if this were not enough, ammonia is apt to decompose, evolving highly explosive hydrogen. It is very difficult to completely stop the leakage of freon and ammonia, especially during transportation by rail when inevitable jolting loosens joints. As to air, it does not cost anything, is safe, and its leakage does not affect the quality of frozen products. In short, the new machine has a great number of advantages. In recent years, patents for the above invention have been granted in nine countries: Japan (No. 482,493), USA (No. 3,213,640), France (No. 1,361,436), Italy (No. 694,344), Great Britain (No. 986,746), Canada (No. 711,457), Sweden (No. 196,299), Switzerland (No. 425,847) and Belgium.

Meanwhile, the inventors have continued to improve the design of the machine (the number of Inventor's Certificates covering various improvements is steadily growing) and search optimum ways of using it.

In 1965, at the experimental factory of the All-Union Scientific and Research Institute of Food Canning and Vegetable Drying Industry at Biryulevo, near Moscow, many freshly prepared dishes were frozen; red cabbage, beet and horse-radish salads, borshches, rassolniks, mushroom soups, fritters with curds and meat, goloubets, boiled chicken with white sauce, etc. After defrosting, experts could not tell frozen food from fresh. It had 3 to 4 times less microbes, and 3 to 5 times less spores than the fresh food.

These advantages are due to fast freezing. At conventional refrigerating plants, freezing takes 4 to 5 hours, while the TXM-300 does the job for 30 min.

Slow freezing causes the formation of relatively big ice crystals between fibres of meat. The ice crystals damage the tissue so that it cannot regenerate after defrosting, but when freezing is fast, the ice crystal structure is fine-grained. Tests conducted at the Odessa Technological Institute of Food and Refrigeration Industry indicate that such fast freezing in no way impairs the quality of frozen meat; meat even becomes more succulent. Moreover, as a result of fast freezing, a crust of ice is formed on meat, protecting it against drying. Freezing losses, which usually constitute 3 per cent of the total weight of a product have been reduced threefold.

The introduction of the new machine, however, gave rise to some objections. "The TXM is not paying", contended fish canners at a conference. "It consumes too much energy per calorie of cold it produces".

Yes, they are right in a way. They forget, however, that the TXM does not occupy half the refrigerator ship like other machines, thus substantially increasing her carrying capacity. This fully makes up for the excessive consumption of energy. What is more, you never can tell during the fishing season when fish is going to appear. Conventional refrigerating machines have, therefore, to work all the time, while the TXM can be started instantaneously. Having it aboard, you need not keep it running without a break.

TXM-type machines make it possible to create mobile meat-packing plants which transport frozen meat to the consumer. Saving on forage, simplification of transportation and reduction in live weight losses, offered by the new method, is obvious.

When gathering cherries, strawberries or green peas over vast areas, a truck-mounted TXM-300 can rapidly freeze the crop, which is packed in thermally insulated containers. The containers, like thermos flasks, pre-

serve products for 17-18 days. Thus, the possibility of a product being wasted is ruled out completely, no matter how big is the crop.

Of course, food industry is not the only field of application of turbocooling machines, and, as the inventors themselves think, not the most important.

When rubber is vulcanized in built-up moulds, part of the rubber stock is squeezed out forming a filmy fringe over the perimeter of the mould, known as rind or spew. This fine film has proved to be a serious handicap to automation and mechanization, because the rind has to be trimmed by hand, with shears. True, for some articles it has been possible to use a more progressive method: freezing and treatment in tumbling barrels. Articles placed in freezing chambers are treated with liquid nitrogen, then transferred to revolving barrels. Colliding with one another and with cast iron ingots, the articles get rid of the rind. This method is used, for example, in the manufacture of certain articles at the Moscow "Caoutchouc" plant, but it takes one litre of liquid nitrogen to treat one kilogram of rubber; then there is the problem of transporting liquid nitrogen. This runs into a tidy sum if we consider that some 350 tons of rubber are treated with cold annually. Besides, nitrogen freezes not only the rind but also the article proper. The article is embrittled, its surface becomes susceptible to damage and is soiled in the course of tumbling.

At the Volzhsk branch of the Rubber Industry Scientific and Research Institute, a new apparatus has recently been developed for removing rind by grit. Articles are slightly frozen by a stream of cold air from a TXM-300, then blasted with grit having a grain size of 0.1 to 0.4 mm. When treated by this method, articles remain intact and retain their elasticity, the duration of the process is reduced four times, as compared to that

of tumbling, and only amounts to 5 or 6 minutes; liquid nitrogen is needed no more and the apparatus can be easily incorporated into an automatic line. The employment of the apparatus at the "Caoutchouc" plant alone may effect an annual saving of 40 thousand roubles, the equipment paying for itself in less than 18 months. The total annual savings in the whole of the rubber industry will amount to 2 million roubles.

Turbocoolers will be still more effective in mine engineering. The access to mineral deposits is becoming increasingly difficult; these often have to be worked in extremely complex hydrogeological conditions, at profound depths or in quick ground permeated with natural brine. To sink a shaft, miners drive freezing columns into quick ground, which are circumferentially arranged metal pipes carrying a coolant. A refrigerating plant installed on the surface puffs night and day, and slowly but surely each pipe is wrapped in ice like a cocoon. The cocoons are then fused into a cylinder-shaped frozen mass. Wash is pumped out through the middle portion of the cylinder. The walls are concreted and the quick ground remains outside. This method of freezing is not as simple as it may seem. First, refrigerating plants of the required capacity are too cumbersome. They have to be transported to the site unit by unit, then assembled, supplied with water and protected against bad weather. Expensive structures and equipment used for the purpose soon become unnecessary. Besides, water is not always available.

Furthermore, conventional steam-compressor refrigerating plants fail to provide for sufficiently low temperatures to properly freeze quick ground permeated with brine. As a result, sections of a shaft remain surrounded by unfrozen quick ground, which is most hazardous. In addition, coolant-carrying pipes must be as thin-walled as possible because every extra millimetre increases

their thermal resistance, thus adversely affecting heat transfer. Thin pipes, however, are apt to break and, as a result, brine rushes in, washing away the ice envelope; it is followed by treacherous quick ground. Such accidents are common. In these cases, miners have to abandon the shaft which is near completion and start from scratch in some other place. Due to accidents, the actual cost of sinking shafts is in some cases several times higher than estimated.

If air is used as the coolant, a pipe rupture would not lead to an accident; air cannot wash off anything. TXM-type machines ensure deep freezing, require no water and are easily transportable. To demonstrate these advantages, engineers at the Donetsk All-Union Scientific and Research Institute of Organization and Mechanization of Mine Engineering have set up a special test bench in their experimental shaft, simulating shaft sinking through quick ground. It turned out that it took four days for a TXM-type machine to completely freeze a shaft, while it takes from two to four weeks to do the job by using conventional methods. In short, the cost of freezing is reduced more than twice. Estimates made at the Bereznikovo potassium plant indicate that the introduction of the new machine saves half a million roubles on every two shafts. To render the air freezing method practicable, it takes much more powerful machines than the TXM-300. Inventors see no difficulty in manufacturing such machines. As a matter of fact, turbocoolers can be made 100 times more powerful without being too large.

Quick ground is not miners' only headache. Another serious problem is the raising of the rock temperature with the depth. With every 33 metres of depth, it rises on the average by one degree. In some shafts of the Donets Basin, coal is extracted from depths of 700 to 1000 metres, and some still deeper mines are envisaged.

For instance, the "Scheglovka-Glubokaya" mine is expected to be 1500 to 2000 metres deep. Temperature in it may reach 60°C. To provide miners with tolerable working conditions, the air will have to be cooled. This is where turbocoolers come in. Apart from being the most convenient for the purpose, machines do not use any coolant capable of evolving toxic and explosive gases.

In mechanical engineering, turbocoolers will appreciably simplify and facilitate low-temperature treatment of steel alloys. To promote complete conversion of residual austenite into martensite, the former has to be tempered at least three times. This, however, can be done at once, if the metal is cooled down to —120°C. Sometimes liquid nitrogen is used for the purpose, but this method involves transportation problems and nitrogen is apt to rapidly evaporate, an undesirable feature. Deep freezing can be also instrumental in restoring various gauges and end blocks. Treated with a stream of freezing air, they swell, as a result of a rearrangement of the metallographic structure, and it only remains to remove the extra layer by grinding them to size.

To repair an open-hearth furnace, one has to put it out. What is more, it has to be cooled down. This, however, takes too much time. Repairmen boldly make their way through the infernal heat. But if a refrigerating plant is brought in and the furnace is blown with freezing air, the thin outer layer of the furnace lining will rapidly cool down and it will become much cooler inside. Once the repair is over, the furnace can be heated as rapidly as it was cooled, since very little heat is lost by implementing the new method.

Turbocoolers will accelerate placing of concrete: construction workers will not have to wait for good weather to start working; they themselves will be able

to create the required temperature conditions. Thickening ice over frozen rivers and lakes to cross them, freezing access roads to temporary bridges, which usually turn into impassable mires and speedy erection of ice domes for stores and circuses, can all be done by using refrigerating plants.

Turbocoolers are the most promising for civil housing. Powerful centralized cooling plants in each residential district will supply apartment houses with hot air in winter and cold air in summer. Boiler rooms, cast-iron radiators, water pumps and other heating equipment will all become redundant. The air will pass directly through ventilating grates. Thus, overall air-conditioning will become a reality, i.e., maintaining a required temperature will be accompanied by the aeration of rooms. At the same time, individual electric refrigerators will no more be necessary either. They will be replaced by cheap and simple built-in cabinets. You will only have to open a tap, and a stream of refrigerated air will instantaneously freeze the products.

In a more distant future, turbocoolers will condition the air in entire cities built in sun-scorched deserts under the cover of light plastic domes.

The limitless potentialities of the new refrigerating machine have been estimated at their true worth both in our country and abroad. The machine has been inspected and highly praised by such celebrities as Academician M. Keldysh, President of the USSR Academy of Sciences, Academician V. Kirillin, Deputy Prime Minister, Academician B. Stechkin, the father of the jet engine theory, Academician P. Kapitsa, Head of the Institute of Physical Problems, and others. At the Exhibition of Economic Achievements of the USSR, the machine was awarded a First Class Diploma and 14 medals. It was highlighted at the Soviet pavilion

at the Leipzig Fair in March of 1966, and in October of that year was widely acclaimed in Japan; in April and May of 1967, it was a great success at the International Welding and Ship-building Exhibition in London.

"The TXM-300 is highly perspective", remarked Dr. Opitz, Technical Manager of West Germany's "Guteshoffnungshütte", at the Leipzig Fair.

"The potentialities of the TXM-300 are indeed limitless", stated Mr. Szydlowsky, President of the French "Turbomec" Company, during his visit to Moscow.

An eminent American expert on thermodynamics wrote, "The Russian cycle, as the Englishmen call it, is a superbly simple air refrigeration cycle. Despite the little information I have, I think that the TXM-300 is a most original machine with a very interesting thermodynamic cycle".

JET ENGINE IN A FIRE HELMET

Jet stream extinguishes fire

First fire stations appeared in Russia in Pushkin's time, some 150 years ago. Since then, fire alarms have been sending firemen to the scene of disaster. Of course, their equipment has changed dramatically. Today they are alerted by radio instead of tolling bells, and speedy red fire-engines have replaced squeaky horse-driven wagons. One cannot deny that certain progress has been made, yet fire extinguishing techniques remain rather primitive.

Although firemen arrive at the place of the fire very quickly, it takes them plenty of time to put the fire out; as a result, whatever they are trying to save gets

soaked so much with water that at times the water causes much more damage than the fire, especially at food or industrial warehouses.

Increasing the power of machines is the most effective way to speed up any kind of work, including fire fighting.

In the past, aircraft designers worked hard to improve piston engines; fire control engineers, on their part, developed increasingly powerful pumps. However, the era of the new turbojet engines, far more powerful than piston engines, that revolutionized aviation and enabled pilots to break the sonic barrier gave the idea to fire control engineers who decided to experiment with jet engines. Not without good reason, because jet engine is, in fact, a powerful blower capable of exerting as much as tens of thousands of horse-powers. You only have to add water to the air jet, and the engine will turn into a pump of enormous capacity.

The idea was advanced by Anatoly Trapeznikov, Head of the Fire Department in Novosibirsk.

The jib of an ordinary truck hoist was replaced by discarded turbojet engine. The engine could be easily pivoted in all directions. Two welded tanks were installed, each having a capacity of 1400 litres, one containing kerosene to fuel the engine, and the other, water. The water tank was connected to the nozzle of the engine through a pipe. The air jet sucked in the water, atomizing and evaporating it and the scalding jet of steam fiercely assaulted the fire putting it out in only 10 to 15 seconds. The fire-engine stops against the burning building and like a gun is aimed straight at a window. A stream of snow-white steam so powerful that it can easily scatter a burning pile of logs assails the fire.

Special tests have corroborated the efficiency of this new original method of fire extinguishing. Its most im-

portant advantage is the relatively low water consumption. Apparently, jet engines make a break-through even in fire extinguishing.

According to the British aviation monthly "Flight", similar tests are also under way in Great Britain.

JET ENGINES CLEAN RAILROAD TRACKS

Hot jet stream thaws out snow-drifts

In the steppes of Kazakhstan, snow blizzards are common. They often keep the rail track of the Sokolovsko-Sarbaisky ore-dressing plant snow-bound. The maintenance crew cannot clean the track without outside assistance, so workers from the plant are sent to help. This, of course, reduces productivity at the quarries.

An aircraft turbojet engine BK-1 mounted, as suggested by Zh. Tleugabylov, V. Pasko and V. Niekhelman, on a four-axle flat car can effectively combat snow-drifts. Two hydraulic jacks taken from MAZ-525 dumpers support the frame of the engine and set it to any desired working position.

The outgoing gases having a temperature as high as 400°C are directed by means of a special nozzle to the rail track and blow the snow away.

6. Machines Dig Earth

In the ancient world, it took millions of slaves centuries to build dams and canals. Nowadays even if the whole of mankind had become diggers, it would not be able to cope with the immensity of the excavating work under way all over the world. Colossal foundation pits for hydroelectric power plants, thousands of miles of irrigation canals, open-cut mines resembling dry lakes, all involve billions of cubic metres of earth and rock which is excavated, crushed and transported over long distances. In the meantime, engineers are coming up with new projects of tunnels extending for many miles to link up continents, dams built across straits and seas, and artificial islands. These projects cannot be realized unless much more powerful and efficient digging machines are developed, based on the latest scientific and technological achievements.

BEAM-CONTROL DEVICE

New Soviet optical instrument doubles the efficiency of bulldozers, planers and digging machines

Most people dealing with heavy and powerful mechanisms do not seem to care much about instru-

ments mounted on them. Any tractor, bulldozer, coal combine or track packing machine operator is primarily interested in the power, speed or operating width of the new machine he is going to operate. Whether it is provided with a revolution counter, a fuel indicator or an oil pressure indicator is less important for him. In a way he is right, because it is the speed and power of a machine that characterize its efficiency. Once he knows them, it is not difficult to figure out if he can exceed the quotas and get a higher wage. Although all sorts of counters, meters and indicators do help a little, some operators think they can do without them anyway.

This picture shows so-called "inflatable excavator" invented by Muscovites A. Karpov, N. Hansen and V. Kartsev (Inventor's Certificate No. 188,907). A deflated folded gas-tight sheath is placed in a narrow ditch. Then, the sheath is filled with compressed air or liquid. The upper layer of the ground is torn up at once forming a long deep trench

It should be wrong to assume, however, that all instruments without exception do nothing but merely watch and register the performance of other mechanisms. Inventors have developed instruments on which the efficiency of a machine depends much more heavily than on the power of the main motor. An excellent example of such an instrument is furnished by PUL, the Russian abbreviation for the beam-control device, invented by Prof. S. Zuckerman, D. Sc. (Tech.), of the Leningrad Institute of Fine Mechanics and Optics.

One day a group of scientific workers from the Northern Research Institute of Hydraulic Engineering and Reclamation came to the optical instruments laboratory in which he worked to ask for advice. As you very well know, land reclamation involves digging hundreds of miles of trenches, ditches and laying hundreds of miles of drain pipes, all with a certain gradient. The gradient should be maintained as accurate as possible, otherwise, water will stagnate in the pipes, choking and sedimentation will occur, and the whole drainage system will be put out of operation. The work procedure, therefore, is as follows. First, levellers mark out the route, take all the necessary measurements, drive pegs into the ground at 10-metre intervals and stretch wire between the pegs, using a level. Naturally, all this is done by hand. After that a ditcher comes into play, and the process then becomes automatic: the ditcher follows the wire, touching it with a feeler. This convenience, however, is very costly: the ditcher has to crawl at a spail's pace lest the feeler displace the wire. Finally, the ditch is ready. One would think that pipes could now be placed into the ditch and the work would be over. Far from it. Despite all the pains taken, the gradient is not accurate enough. Workers therefore use antediluvian spades for the final levelling adjustments.

As seen, the process is extremely laborious and res-

ists mechanization. With hydrotechnical reclamation going on at an unprecedented pace in the Soviet Union, the existing methods can no longer satisfy the requirements of reclamation engineers. So they decided to ask opticians for help. They reasoned, that light-sensitive photocells could catch a ray of light, so why not set up a projector in the field and install a photocell on the ditcher? The photocell can catch the light signal and actuate the controls of the machine. The advocates of this method were also encouraged by the fact that such a system had long been introduced abroad.

In fact, abroad the new method was not widely applied because the intricate arrangement which included a rotating projector and five light detectors failed to be sufficiently accurate. This brought engineers back to the old good ditcher crawling along a wire, though the process was somewhat improved: the ditcher was provided, for instance, with a computer so that even the sagging of wire between pegs could be taken into account. But the process still remained as labour-consuming as ever.

The inaccuracy inherent in optical control seemed almost insuperable, because of one of the basic properties of a light beam, namely, its divergence. This means that the region of equal intensity of luminous energy across the beam, referred to as the equisignal zone, is diffused, so that instead of a sharply defined spot we have a shapeless splotch of light which, regretfully enough, renders such a seemingly simple and effective method of control impracticable. The essence of Zuckerman's invention lies in that he has managed to obviate this difficulty by obtaining an ideally straight line in the divergent beam by means of two rather loose elements. We say two because in his apparatus a beam is split into two halves, upper and lower, each possessing its own properties. The bound-

ary between the two beams is precisely that absolutely straight line which can be used for control. For comparison, imagine a deep vessel with an irregular bottom containing two different liquids which do not mix. Then suppose that the surface of the upper layer is rippled by a wind. Though the upper and bottom surfaces are irregular, the interface between both media will be ideally flat.

A beam-control device comprises four basic units: a projector, a light detector, an amplifier and a control panel. The heart of the device is the projector, or rather its optical system which transforms the light of an ordinary incandescent lamp into two heterogeneous beams. The light detector is a simple combination of well-known photocells, the circuitry of the amplifier is as simple as that of a pocket transistor, and the control panel is standard.

The projector mounted on a special tripod is placed, together with a 6-V accumulator, at any required point in the field. A level is used to adjust the tilt of the device, and a graduated circle sets the beam in the right direction.

A whole team of levellers is now replaced by two persons: a technician who takes care of the projector and a ditcher operator who no longer has to worry about the right depth or gradient of the ditch. The entire system is automatically controlled. The beam that is parallel to the bottom of the would-be ditch is continually aimed at the light detector mounted on a bracket which is welded directly to the working member of the ditcher. Even the slightest deviation of the ditch depth from the preset value produces an error signal. The signal is sent to the amplifier and then to the control solenoids of the working member's hydraulic actuator. As a result, the detector is again aligned with the beam axis. The profiling accuracy offered by the

new method is 2 to 3 cm per 500 m; no additional spade-work is required. The efficiency of the ditcher increases two and a half times and the number of the personnel is cut down 2 to 3 times.

Ditcher operators could also become redundant if the existing machines could be adapted for automatic operation. The trouble is that hydraulic actuators have been provided only for mounted implements, while right and left turns are made by means of steering clutches which only an operator can manipulate. Nevertheless, tractors, excavators and digging machines are now being developed that can be fully operated by beam-control devices. At present, the ditcher operator has to follow the light beam by using a small mirror. It is curious that both beams actuating the photocells of the light detectors are invisible infra-red beams. These are made visible to the operator by having two colour-coded light beams superposed on them: a red beam is superposed on the left one and a white beam, on the right one. All the operator has to do is to follow the vertical line separating the two beams. The technician handling the projector and the ditcher operator can communicate by means of the Morse code. For this purpose, the projector is provided with a lever switch that can be used as a tapper.

The use of the beam-control device is not confined to digging ditches and canals. Experts at a research institute under the Ministry of Transport have decided to use it for controlling track packing machines. These machines are used to periodically correct the buckling of rails caused by passing trains. Since the permissible depth of "ruts" along a rail track is very small, railroad engineers tried their best to achieve an accuracy of no more than one millimetre of gradient per 100 metres of track. The beam-control device passed the test with astonishing results, showing an accuracy of

± 0.6 mm per 150 m of track, i.e., being two and a half times more accurate than required. It takes only seven seconds for a track packing machine equipped with the beam-control device to pack one sleeper. The beam-control device has proved to be particularly advantageous for packing sleepers at track curvatures where measurements are especially difficult. As the machine moves along the curvature, the projector follows the curve, continually maintaining a high measurement accuracy.

Even that does not exhaust the potentialities of the beam-control device. Engineers at the Skochinsky Mining Institute are contemplating the introduction of the device into coal mining for controlling coal combines. At the Foundations and Underground Structures Research Institute, attempts are being made to use it to control tunnel heading machines. At present, heading machines are controlled by means of underground surveying marks and plumbs; this process is extremely difficult and not sufficiently accurate.

Engineers at the Kramatorsk Research Institute of Transport and Lifting Gear Engineering are adapting the beam-control device for use in boring machines. So far, all the working dimensions have been measured by means of dials and scale rules, which is basically a poor method because the deformations of the bed or boring bar, which at times reach substantial proportions, are not accounted for. Only the light beam is capable of ensuring an accuracy to the order of 0.02 mm, when measuring a workpiece 5 metres long.

The beam-control device may be used with equal advantage in planning fields, asphalting streets, in pipe driving, in short, in all operations where a working member has to be moved along a straight line.

In the present embodiment (incidentally, the device is already in serial production in the Urals), the beam-

control device can be mounted on any tractor having a hydraulic actuator with a solenoid slide-valve and a generator or accumulator producing a standard voltage of 12 V.

PICK-HAMMER MADE OF PLASTIC

The discovery made by Candidate of Sciences E. Alexandrov and registered under No. 13 throws new light on the theory of impact elaborated by a galaxy of world-famous scientists, including Newton, Huygens, Hertz and the founders of the elasticity theory Love and St. Venant. Pick-hammers, hammer drills and machines for drilling frozen ground, all percussive mechanisms, will be substantially improved on the basis of the new theory

Science is man's most powerful weapon in fighting prejudices. However, doing away with old prejudices, it sometimes gives rise to new ones which may be no less persistent and pernicious. One of such prejudices, especially trappy for a designer or an inventor, lies in the wide-spread conviction that any more or less serious research calls for the use of extremely sophisticated equipment. Of course, there was a time when the most fundamental laws of nature were discovered with the aid of primitive lenses, tubes and springs made by scientists themselves, when great discoveries were made in barns and garrets. Alas, the romantic period of the history of science has long been over. Today, science is helpless without industry. Cyclopean annuli of particle accelerators, miles-long radiotelescopic antenna arrays, supercomplex cybernetic systems consisting of millions of elements, are all indispensable for modern science. There is a wide-spread opinion that everything lying on the surface has long been discov-

ered, described and thoroughly studied, so nothing more of interest remains. This "theory" has been refuted a thousand times, yet each time its advocates insisted with the blind faith of perpetuum mobile inventors that it had been the last drop of water from the dried-up well.

A few years ago Evgeny Alexandrov, then a lecturer at the Tbilisi Polytechnical Institute, delivered a lecture on mining machines. While explaining the operating principle of a hammer drill, he suddenly stopped short struck by an unexpected idea. As a bolt from the blue, it flashed through his mind why the efficiency of hammer drills had been so low. He also knew now how to raise it. Returning home he made some calculations which convinced him that he was on the right track. On the strength of elementary and absolutely indisputable formulae deduced long ago by no one else but Newton, Evgeny Alexandrov had arrived at the following conclusions: the efficiency of a drilling machine can be increased if the drill stem is divided into several portions.

It remained to put his idea into practice. To test it, E. Alexandrov went to the production centre of the Institute in the town of Kizel. He sawed a drill into pieces before the eyes of puzzled miners, but to no avail. He ran through his calculations over and over again only to find that they were correct. Yet, the drill would not work any better. Why?

"In the final analysis, the development of science needs facts which are inconsistent with the known laws", said the great Russian chemist A. Butlerov. This paradox proved to be true in this particular case, too. The temporary setback with the drill taught E. Alexandrov a most useful lesson which finally led him to a discovery that revolutionized pick hammers, hammer drills and other percussive mechanisms.

To better understand the essence of Alexandrov's discovery, let us recall that part of mechanics which deals with the theory of impact. Ya. Perelman, the author of "Popular Mechanics", wrote that this theory was hard to learn and easy to forget. The only thing that students usually remember about it is that it is a maze of brain-racking formulas. As a matter of fact, there is nothing complicated about it. The theory is based on two very simple propositions.

1. The total momentum of colliding bodies (i.e., the sum of the products of their masses by their velocities) remains constant before and after impact.
2. The coefficient of restitution is constant for every material and is independent of the collision velocity of bodies, as well as of their sizes.

Imagine a ball falling on a hard plate. As it hits the plate, the ball rebounds or, if made of damp clay, sticks to it. In any case the height to which the ball rebounds is proportionally less than that from which it was dropped initially. Correspondingly, the ratio of the velocity of a body immediately after an impact to its velocity just before the impact, i.e., the coefficient of restitution, may vary only from unity to zero. From the above propositions it is easy to deduce all the necessary formulas relating to the energy transmission during an impact, to the calculation of the resultant velocities, etc.

If the first proposition represents a mathematical corollary of the basic laws of mechanics, tested over and again millions of times and each time proved to be correct, the second proposition, on the other hand, is in no way related to these laws, being merely an assumption made by Newton. He experimented with clews of wool, glass or steel balls and assigned them with values of coefficients of restitution, regretfully neglecting, however, the sizes and shapes of the collid-

To prove that Newton was not right, E. Alexandrov demonstrates a simple experiment: balls made of various materials rebound to the same height at an elastic impact

ing bodies. Relying on Newton's infallibility, generations of scientists and engineers only specified these values for various materials. In any college textbook, technical handbook and sometimes even on the reverse side of a slide rule, you may find neatly arranged tables of coefficients of restitution for steel, wood, ivory, glass and plastics. The odd thing about it is that in different books, the values of these coefficients for the same materials do not tally at all! For steel, for instance, they vary from 0.55 to 1. Now, which value is correct? None.

That is the conclusion at which E. Alexandrov has arrived after elaborate and comprehensive experiments. Trying to find exact values of coefficients of restitution is as senseless as trying to determine the exact time of travel from Leningrad to Moscow regardless of whether you walk all that distance or take a plane. It turned out that for any material, be it steel, glass, plexiglass, or ebonite, the coefficient of restitution may assume any value from zero to unity, although in each particular case an impact remains elastic without causing any irreversible elastic deformations. One only has to change in a particular way the shapes and masses of colliding bodies. These conclusions are absolutely contrary to the universally accepted concepts of classical mechanics and the theory of impact.

Simply speaking, Newton made a mistake, and Soviet scientist E. Alexandrov has corrected it.

It should be noted, however, that Alexandrov was not the first to cast doubt on the classical theory of impact. Long before him, St. Venant, Love and Sears also expressed similar doubts, but none of them went as far as to draw definite conclusions.

E. Alexandrov demonstrated that Newton was not right by a simple experiment. Everyone can easily do it. One only has to take a small rod and a stepped shaft. The rod is dropped on the shaft twice from the same height so that the two strike against each other with their end faces. From the thicker end the rod rebounds higher than from the thinner end, thus proving that the coefficient of restitution depends on the shape of a body. If several balls made of steel, ebonite and plexiglass are dropped together on a steel plate, they will rebound to the same height. This experiment can be easily filmed. Balls are dropped in a dark room and filmed by a camera with its shutter fully open and a bulb flash-light flashing twice with an interval select-

ed according to the time of the fall and rebound of the balls. The resulting picture does not leave a shade of doubt about the coefficients of restitution of various materials being the same. This is exactly the essence of Alexandrov's discovery.

Let us not dwell upon rather complicated theoretical reasoning offered by E. Alexandrov, based on the study of wave mechanics of solid bodies through which waves of stresses and deformations propagate at sonic speed after an impact like ripples in water, and see instead what practical results his discovery has yielded. What practical problems are solved by varying within a wide range the coefficient of restitution and other parameters of an impact? Take, for example, an air hammer, the basic tool of a miner, road builder and construction worker. Acted upon by air pressure, a steel striker moves inside the casing of the hammer to and fro, striking against the bit and forcing it through the ground, concrete or rock. Newton's third law of motion holds that "to every action there is always an equal and opposite reaction". Recoil forces proportional to the mass and acceleration of the striker, each time act on the hammer in an opposite direction. To reduce the effect of these forces upon a worker, the hammer casing is made of steel and is so heavy that the weight of the hammer reaches 15-16 kg. Try to hold this pounding monster in your hands for a whole shift and you will see how urgent it is to make a hammerman's work easier. Moreover, frequent heavy strokes rapidly wear out the striker, so it has to be made from the best high-alloyed steels.

E. Alexandrov has proved, however, that during an impact the energy is transferred not by the entire mass of a body but only, to use his expression, by its critical part. Hence, the weight of the striker may be reduced two- or threefold without affecting the power

of the hammer. Vibration is minimized as well (actually the operator does not notice the vibration any more). The weight of a hammer may be reduced by one half by making the casing from a light aluminium alloy. Incidentally, the striker itself may be made of rubber or plexiglass instead of steel. As far as the high strength of the striker is concerned, it is no longer of any consequence: from a simplest combination of rods and springs E. Alexandrov has managed to design "mechanical semiconductors". These semiconductors transfer force and the impact energy only in one direction. These qualities are indispensable for percussive mechanisms permitting in most cases to eliminate vibration and minimize impact loads on components of the mechanisms, thus making them much more durable without using expensive high-quality materials.

The principle of operation of a mechanical semiconductor can be easily understood from considering an elementary arrangement consisting of several small cylinders abutting against one another, with only a small gap between the extreme left cylinder and the rest of them. Let us assume that an impact is produced by the extreme left element, while the others are at rest. Since all the elements have equal masses, the energy of this impact is fully transferred to the extreme right element. (It is like billiard balls arranged on the table close to one another. If the leftmost ball is hit, all the other balls remain at rest except for the rightmost ball which bounces off at the same speed.) Suppose now it is the extreme right element that strikes the others. Instead of sending a pulse and the impact energy through the other elements, it will simply rebound after a mild shock shakes the whole system.

Besides "semiconductors", rods and balls may also produce "impact transformers". Back in the last century, Huygens formulated the following principle:

"A body at rest is imparted as much momentum by a body which is in motion and has a different mass as is the number of bodies placed between them".

In fact, during a direct impact, a body which is at rest is imparted only part of the momentum of another body, and the greater the difference in their masses, the less that part is. If many bodies are placed between those that collide, every two adjacent colliding bodies will differ in mass but slightly. Therefore, the striking body will practically stop and impart most of its momentum to the body which is at rest. So, if the striking body has a small mass, it will rebound at a very high speed.

It is clear now that by means of "mechanical semiconductors", "impact transformers" and by varying the shape of colliding bodies we can obtain any required speed, force and duration of collision. In short, we can change at will impact parameters the way electronic engineers vary currents and voltages.

In the drilling laboratory of the A. Skochinsky Mining Institute of the USSR Academy of Sciences, headed by E. Alexandrov, you can see what looks like an ordinary pick hammer. Although it has a wooden striker, the hammer has already been in operation for a period of time equal to several service lives of an average conventional pick hammer. At the Exhibition of Economic Achievements of the USSR you can see still another pick hammer with a transparent striker made of plexiglass. In the near future, light-weight and almost non-vibrating pick hammers will be made commercially. In fact, it is possible to eliminate vibration even in older models and raise their efficiency. To this end, it is sufficient to replace the old striker with a new one that can be easily made in any workshop. In his review of E. Alexandrov's work, Academician N. Melnikov wrote that "in the pick hammers produced in tens

of thousands a year at the "Pnevmatika" works, vibration is mitigated without any structural alteration of their components by enlarging the slot in the handle and replacing the elastic members by identical ones with specially selected parameters". One of the first batches of light-weight pick hammers is now undergoing tests in Yenakievo, at one of the mines of the "Ordzhonikidzeugol" coal-mining complex.

The same method was effectively used to reduce the weight of chipping hammers, riveters, tools for dressing and reinforcing welds on thin-walled structures made of high-strength materials by high-speed impact treatment, etc.

E. Alexandrov's theory opens the way for the development of percussive electric machines, for instance, electric hammers whose kinematic chain is fully protected against impact loads. These loads have been the cause of frequent breakdowns, thus barring the introduction of electric hammers into production. The employment of recently developed electromotors with a reciprocating core, however, should eliminate the crank mechanism, and the electric hammer may then become as reliable as its pneumatic counterpart. It will be much more convenient in use, as the noisy large compressor and thick rubber hoses can be replaced by a generator and a thin cable.

A classical example of a "tip-of-the-pen" discovery, that is one made by means of calculations, is the discovery of Neptune by Le Verrier. E. Alexandrov has made a similar discovery in the field of drilling machines. Until recently it has been universally accepted that light-weight bore hammers operating on the principle of an ordinary chipper could be used for drilling hard and friable rock only to a depth of no more than 4 to 6 metres. The impact energy could not be transmitted deeper than that, it was believed, since it was totally

absorbed by the long drill rod. Meanwhile, the need for deeper holes is rapidly growing, especially in large-scale rock blasting. The job was done using more sophisticated down-the-hole percussion machines developed at one time at a research institute of the Siberian Branch of the USSR Academy of Sciences. Of course, a down-the-hole mechanism is of a more complicated design than a drill which is little else than just a steel hexagonal rod. Therefore, the hole it drills is always wider than required. Instead of holes 65 mm in diameter, these machines produce larger holes with a diameter of at least 105 mm, which is a disadvantage, first, because the productivity falls fourfold and the number of drillers has to be increased accordingly, and second, because the blasting of such wide holes produces ore lumps as big as 3 to 4 metres. To extract these lumps, they have to be crushed again, which consumes 1.5 to 2 times more explosive than was used for the first blast. Rotary drilling with bits is no better: the cost involved is too high, the driving speed and durability of bits are low, and holes produced are too big.

By simple reasoning, E. Alexandrov has proved that the longest rod is unable to absorb too much energy. Had it been, as many were inclined to think, it would have melted at once. So, another loop-hole had to be looked for through which the energy escaped. E. Alexandrov soon found it. This happened to be the drill-rotating-and-feeding mechanism. After a slight modification which can be easily done at any mine workshop the same machine could drill a hole as deep as 100 metres instead of mere 4 to 6 metres. It effectively drilled a number of test holes at the Krivoy Rog iron ore basin.

The USSR Academy of Sciences has described Alexandrov's work as one of the most important ventures completed under the auspices of its Technical Sciences Branch.

It is curious that when E. Alexandrov first applied to Academician I. Artobolevsky, an authority in machine mechanics, for advice, the latter tried to dissuade him from taking up the theory of impact. "No use wasting time, there is nothing you can add to this theory", he said. Shortly afterwards he admitted his mistake and became Alexandrov's ardent supporter. His enthusiasm was shared by Academician N. Blagonravov, Head of the Institute of Mechanical Engineering under the USSR Academy of Sciences. "I never believed new discoveries were still possible in this field," N. Blagonravov said then.

E. Alexandrov has made his discovery in a very simple way. It can easily be demonstrated with the aid of simplest models. At the same time, this discovery has made a tremendous impact on the development of a whole family of machines. The benefit to the national economy is beyond calculations and it is another striking proof that space research and nuclear physics are not the sole fields that may be rewarding for a hard-working inventor or engineer. It shows that important discoveries may be also made in such a prosaic and seemingly well-covered field as mechanics.

LEAPING WHEEL

Punching irrigation canals

Irrigation is almost invariably the guarantor of rich harvests. In the USSR, irrigation planners envisage watering millions of hectares of land.

The construction of irrigation systems, however, must be worth the expense, just like any other economic project.

The most labour-consuming part of flooding irriga-

tion work is the digging of tens of thousands of kilometres of canals and feed ditches.

Picture a dredger or a special ditcher that moves across a vast field leaving behind it a ditch smelling of fresh earth, with loose vertical walls and mounds of dug out earth on both sides of the ditch. To give the walls the right slant, they have to be trimmed manually, with spades, then tamped, and the excavated earth scattered or transported away. All this makes work slow and costly. There is an urgent need to mechanize all these operations.

In an attempt to solve the problem, Leningrad inventors O. Savinov, M. Zeitlin and A. Luskin have created a highly original device (Inventor's Certificate No. 123,991). It was in no way a combination of several machines operating after the old fashion. The inventors gave up the traditional digging principle altogether in favour of a totally new method.

Imagine a huge metal wheel with bevelled edges that looks much like a turbine disc. As this wheel rolls on the ground, it makes, or rather presses, a deep irrigation ditch. The latter's profile corresponds to that of the wheel, the walls are smooth, hard and with the right slant; in addition, there is no dug out earth to get rid of. The machine completes all the work at one go.

Of course, if the inventors relied solely on the wheel's weight, they would have to make it so heavy that it would never move at all. In practice, the wheel is very light and consists of an open-work metal frame covered with sheet steel. Inside the wheel, mounted on its axle, is a vibrator actuated by a special motor. The vibrator produces directional vibration, making the wheel bob up and down and press itself into the ground.

The wheel, which is the main working member of the machine, is fitted on an axle mounted in slots of a platform towed by a tractor. When the ground becomes

harder or a deeper ditch has to be made, special springs act upon the axle imparting to it some of the platform's weight, and if this is not sufficient, the platform can be made heavier by filling its ballast boxes with sand.

The new machine has been turned over by the Committee for Inventions and Discoveries to the Ministry of Agriculture. It will certainly be of good use to irrigation engineers.

EXCAVATOR DRILLS DAMS

Building a hydroelectric power station without excavators and suction dredgers. Dams around chemical plants

Colossal consumption of labour, cyclopean earthwork involving millions of cubic metres of excavated and removed earth and millions of tons of reinforced concrete to fill the body of a dam, invariably accompany the building of potent hydroelectric power stations supplying cheap power to plants and houses, collective farms and railroads. Hydroelectric power stations are the biggest structures of today. Their builders are justly proud of the scope of their work. Now what about their designers? What are they to be proud of? Is it indeed necessary to have endless lines of dump trucks on the site, or excavators incessantly swaying their shovels, suction dredges with their mile-long sludge lines and a host of bulldozers, scrapers and planers?

First, let us see what actually is the task of hydroelectric power station builders. To cut the long story short, all the problems practically boil down to calculating the precise depth of permeable ground and its removal after diverting river water and draining the foundation area by a system of bypasses and levees and filling the excavated area with reinforced concrete. This

is what all digging machines and trucks are needed for.

As a matter of fact, everything can be done in a far easier and cheaper way. Why not, for example, cut a few parallel deep ditches one or two metres wide where we want to erect a dam and fill them with an impermeable material, such as concrete? Thus, we shall have a somewhat special kind of a dam almost without doing any earthwork and using much less concrete. A very tempting and simple idea promising enormous savings and a tremendous stepping up of the building process. Incidentally, this idea is not as new as it seems. A few years ago, an American firm indeed tried to put it into practice, but went bankrupt as a result. The trouble is that we are yet unable to dig sufficiently deep and narrow ditches. It is a sad truth that although we launch rockets into space, have mastered cybernetics and are in the process of solving the mystery of albumin, we nevertheless lack means to tackle such a simple problem. American engineers have tried to drill a series of adjoining vertical holes, but in vain. This is because a drill never goes straight: as it encounters solid inclusions or, on the contrary, voids, it keeps swerving from its path. Thus, instead of a continuous ditch it produces a chain of holes that looks like a tattered fringe or a comb with bent teeth.

The creation of a machine capable of drilling strictly vertical holes could revolutionize hydraulic engineering. The challenge was taken by a group of hydraulic engineers. It included Semyon Milkovitsky, a well-known inventor and currently Head of the Kiev Branch of the "Gidroproekt" (a hydraulic engineering design institute), Peter Neporozhny, now Minister of Power Engineering and Electrification, and engineers E. Kravtsov and R. Tkachenko, who at that time worked at the Kakhovskaya Hydroelectric Power Project. The group was granted Inventor's Certificate No. 142,210, the

invention bearing a seemingly prosaic title "Device for Positioning Boring Tool By Means of Guides".

However, when the device was examined by experts, there were tears in Academician Winter's eyes. Said the old man, deeply moved: "This invention will shake the world".

Now picture a common, mass produced bucket crane with its boom removed. The boom is replaced by a frame comprising a welded girder made of two steel pipes. The girder can only move in the vertical direction because it rests on two pairs of cast-iron rollers incorporated into the frame. Also vertically moving along the girder is a TM-type boring mechanism which grips the guides like a rest grips the bed of a lathe. The boring mechanism comprises a 100-kW electric motor with a power supply cable, a planetary reduction gear, and a rock-crushing bit. By winching the welded girder up and down, one can regulate the depth of the ditch being cut.

The crushed ground is forced downwards by gravity and by a stream of drilling mud.

From the bottom, it is sucked up through one of the girder's pipes by an air stream generated by two compressors. The other pipe removes the pulp.

Having drilled a hole, the machine makes a step forward and the cycle is repeated. A separating distance gauge moves together with the boring machine and separates that portion of the ditch which is then filled with concrete. The machine can operate both on land and water. In the latter case, the boring machine is mounted on a floating platform held in position by steel jack legs. Being heavier than water, concrete simply squeezes it out of the hole and fills the remaining free space.

As a result, we have a narrow concrete fence reaching down to the impermeable layer. Several such fences

interconnected with transverse concrete beams for better rigidity can replace the huge monolithic ferroconcrete dams. Incidentally, in places where the permeable ground thickness reaches a hundred metres and more, it is the only way of building a dam: carrying away hundreds of millions of cubic metres of ground would be too costly, and if water seeped under the dam, it would simply wash it away.

The new machines are now manufactured in Kiev and Chelyabinsk. According to economists' estimates, the cost of earthwork will go down three-fold.

These machines will be also of great use to chemical engineers as some chemical plants have to be surrounded with screens extending for miles to check the pollution of air with chemical waste. To do this, ditches are dug as deep and wide as ship canals so that one wall can be coated with a thin layer of clay, after which the ditch is filled up again. A machine equipped with the above "device for positioning boring tool by means of guides" may be a very economical solution to this problem because conventional excavators cannot cut a deep and narrow trench.

FIRE-SPITTING EXCAVATOR

Experts at the All-Union Digging Machinery Scientific Research Institute in Leningrad have built an excavator which works just as well in winter, when the ground is frozen, as in summer

Rotary bucket excavators are perhaps the most efficient digging machines. Of late they have been most extensively employed in open-pit mining. Removing every hour thousands of tons of ground and rock, they lay bare coal seams and ore beds, thus making it possible for other machinery to be used.

It should be remembered, however, that in the north and in many parts of the northern temperate zone winter lasts for several months. The frozen ground does not yield to the teeth of such excavators, so these powerful, efficient machines remain idle for the long winter periods.

To make them operable in winter conditions, designers have to substantially augment cutting forces along the edges of buckets, increase the power of main drives and enhance the endurance of the entire machine, these measures inevitably resulting in a greater weight of the excavator.

This can well be illustrated by an example. The German Democratic Republic produces a rotary bucket excavator with a capacity of 1700 cubic metres per hour. It weighs 370 tons; the power of the engine that drives the excavator rotor amounts to 250 kilowatts. Another version of the machine, having the same capacity but designed to cope with ground twice as hard, already weighs 630 tons, and its drive power is 500 kilowatts. From this we may say that the weight and the power of an excavator are directly proportional to the hardness of the ground.

Yet this simplified way of solving the problem is very expensive and uneconomical, keeping in mind that for the greater part of the year excavators tackle thawed ground.

Another way of approaching the problem is the use of so-called flame drills which effectively cope with frozen ground and hard rock. Flame drills were developed at the Kharkov Aviation Institute (Inventor's Certificate No. 165,148) and by a team of specialists from the Soviet Central Asian Republic of Kazakhstan headed by A. Brichkin, Corresponding Member of the Academy of Sciences of Kazakhstan. Despite their enormous destructive power, flame and thermo-reactive

drills have an intolerable disadvantage in our age of mechanization and automation: they are operated manually and, what is worse, the scattered rock is also removed by hand. Clearly, this method is totally impractical for removing millions of cubic metres of rock.

Thus, we have two types of mechanisms for the purpose. Mechanisms of the first type are highly efficient and fully mechanized, but cannot cope with frozen ground. Mechanisms of the second type can cut granite like butter, but still need manual labour. Why cannot these two mechanisms be combined, their advantages used and deficiencies eliminated? This was done by two Leningrad inventors, Victor Ilgisonis, Head of Laboratory at the All-Union Digging Machinery Scientific Research Institute, and Leo Livshits, a leading designer at the same Institute. They have patented a rotary bucket excavator (Inventor's Certificate No. 233,547) employing the two foregoing principles: first, it softens the ground by open flame and then extracts it in the conventional manner.

An ordinary rotary bucket excavator is equipped with an additional fuel tank, a compressor and a system of flexible hoses which supply fuel and air to nozzles mounted on fixed sectors on both sides of the rotor. Before putting the machine into action, the operator ignites the nozzles and, without switching on the rotor, gives a few sways to the boom. After the ground has warmed down to the cutting depth, the operator starts the motor. Henceforth the ground is continuously removed, as the heating power of the nozzles is selected so that the normal operating cycle of the excavator is not impeded.

"Fire-spitting" excavators effectively cope with frozen ground even if they encounter patches of hard rock. If necessary, the operator can even cut narrow

ditches in frozen ground by increasing the supply of fuel and compressed air to the nozzles.

The economic gains are obvious, it is easier by far to equip an excavator with a fuel tank and nozzles and have it operating all the year round than to build weighty and powerful giants which will be not profitable in summer.

7. Machine-Making Machines

Man explores space and depths of the ocean. He penetrates miles deep into the Earth's crust to extract coal and oil. Automatic probes examine the human heart and remote planets. These remarkable technological achievements have one thing in common: they have only been made possible by specially designed mechanisms and machines. The mechanisms and machines can only be made by machine-tools, presses and other metal-working equipment. Hence, the leading role played by the machine-tool industry is indisputable. It is the scientific and technological level of machine-tool manufacture that ensures the development of all other branches of mechanical engineering.

In 1908, the entire industry of tsarist Russia had no more than 100 thousand machine-tools; on the eve of the 50th anniversary of Soviet power, the country had 3 million machine-tools, i.e., 30 times more. In 1913, only 1800 machine-tools of the simplest design were manufactured in Russia; now the annual output is two hundred thousand, most of these being high-speed, precision, automated machine-tools.

LIGHT-CONTROLLED MACHINE-TOOL

Inventors from the Institute of Fine Mechanics and Optics in Leningrad were the first to use a light beam as a linear standard. This beam simplifies and makes more accurate the boring out of large-size parts, the centering of bearings, the grinding of guides and the eliminating of flatness errors of bench plates

We have already spoken about PUL, the Russian abbreviation for beam-control device, an invention of Prof. S. Zuckerman from Leningrad.

Now, we dwell on the application of PUL in the metal working industry.

Prof. Zuckerman's laboratory was full of projectors, like the illuminator's booth in a theatre. These were different models of PUL designed for different purposes. Their number steadily grows.

Prof. Zuckerman opened a folder which contained patents of his invention (Inventor's Certificate No. 201,936) from six countries (British Patent No. 1,094,624; Italian Patent No. 736,442; Canadian Patent No. 750,108; Federal Republic of Germany Patent No. 1,463,379; United States Patent No. 3,452,207; and French Patent No. 1,411,945).

Prof. Zuckerman explained that the basic advantage of PUL was the utmost simplicity of its design and the cheapness of its components. The light source, for example, is an ordinary filament lamp. It costs only a few kopecks, yet the range of the device is quite substantial. For instance, even in broad day light in southern latitudes, a 20-watt lamp has a range of 700 metres. One day, during field tests, Prof. Zuckerman and his colleagues were caught in a dust storm, but even then PUL continued to operate a machine at a distance of 300 metres. At this point, the Professor interrupted his

V. Prokhorov, Manager of the "Electrodetal" plant in Saratov, has invented a mechanism the size of a typewriter, as powerful as a crank press weighing about two tons

story and nodded to an assistant. There was a click of a switch and we saw a circle of light on a wall, sharply bisected by a vertical line. The projection of this line was in fact the basic reason for designing of this device.

Every schoolboy knows that a beam of light travels in a straight line. Inventors have long been trying to

make use of this property for control purposes. But despite its apparent simplicity, it could not be used successfully until recently. The reason is that a beam of light which seems to be an ideal straight line is nothing but a geometrical abstraction. It is only an imaginary axis of a light beam that may at best be regarded as a straight line. As an actual physical phenomenon, however, a light beam is always a widening cone. True, designers have been trying to reduce the divergency by improving optical systems, but this can only be achieved to a certain extent because of difraction which itself stems from the wave nature of light. Is, then the reducing of the initial diameter of the beam a way out? It is a way out, of course, but only provides a partial solution, for as we do so, the power of a signal that reaches a receiver is reduced accordingly, so the latter would not operate. Unsuccessful attempts to reduce the ever growing size of the light cone forced engineers to locate at least the axis of the cone with the aid of several photocells. This, too, was of no avail because of uneven deterioration of photocells and the ensuing distortion of their characteristics.

Prof. Zuckerman's team chose a totally different approach: they decided to divide the cone into two halves having different properties (see Chapter 6).

The optical circuit of PUL consists of a 20-watt filament lamp whose light is sent via two identical systems of lenses, prisms and mirrors to the lateral facets of a prism. The sharp edge of this prism is placed in the focal plane of a mirror-lens objective. Before reaching the facets of the prism, the beams are modulated, i.e., interrupted by two rotating toothed discs. The discs may rotate at different speeds, have a different number of teeth or have these displaced by one half of a pitch with respect to one another. If the objective of a receiver rigidly fixed to a working member of a machine being

controlled is placed precisely upon the axis of the projector, it receives equal quantities of energy from both beams. If the objective is displaced, the balance is disturbed, the difference signal is amplified and makes the working member reassume its position upon the axis of the beam.

Having only one lamp and one receiver, PUL is affected neither by deterioration of the photocells, nor by fluctuations of the supply voltage.

PUL was first tried on digging machines. The device accuracy, however, proved to be so high that it was decided to use it for the control of precision machine-tools. At that time, the Novo-Kramatorsk Plant had to produce a gear with a diameter of 18 m for a walking excavator. As no machine-tool can cope with such a large blank it was suggested that the machine-tool be moved around the blank. In the centre of the blank PUL was installed, and the teeth were cut relative to one another to an accuracy of five angular seconds.

Generally speaking, PULs make it possible not only to automatically measure deviations from preset dimensions or geometrical forms, but also to automatically obtain these dimensions or shapes.

It is known, for example, that advancing the headstock of a big boring machine by 5 metres displaces the axis of the boring bar by 0.2 to 0.5 mm due to deformations of the machines; this, in turn, displaces the axis of the hole being bored. Today, this drawback can easily be overcome. A graduated scale is attached to the bed. The required dimension is set by a micrometer, i.e., the PUL projector is displaced accordingly. The PUL receiver is attached to the headstock. As the headstock reaches the preset point, it is automatically stopped by the command of PUL. The accuracy of positioning is 0.03 mm, which is 3 to 5 times higher than usual.

Let us assume that we have to grind or mill guides of a big machine-tool. The spindle of an abrasive disc or a milling cutter is set in a special carriage mounted on a support. The PUL receiver is rigidly fixed to the carriage. The support is placed upon roughly machined guides and is drawn along these by a cable. The axis of the abrasive disc or the milling cutter can be displaced vertically by a special mechanism. The projector is switched on, and the grinding begins. Although the support moves along a rough surface, the position of the carriage in the vertical plane is continually corrected by the linear beam; thus we obtain absolutely straight guides. Tests ascertained an accuracy of ± 0.05 mm over a length of 20 m.

PUL has also proved to be highly effective when used on vertical lathes; it ensured a high dimensional accuracy of large-size cylindrical parts.

PULs easily help to solve the problem of coaxiality or parallel placing of axes of several bearings. One simple example is the linear adjustment of the bearings of the main engine shaft in a ship, such a shaft can be 30 to 40 metres long and be mounted on 8 bearings.

Other possible applications of PULs in metal working include the control of wall thickness when turning or boring pipes and the flatness control of large bench or base plates.

It should be noted that PUL has attained the highest possible accuracy at least when working out in the open. Beam deflection errors resulting from fluctuations in the atmospheric pressure and temperature have rendered further attempts to raise the device accuracy impractical.

As regards a laser beam, its brightness can also provide a reasonably good accuracy, although it is twice as less as that attained by PUL. The employment of a laser in PUL is bound to raise substantially the operating range of the device.

WRIGGLING MACHINE-TOOL

Heating and cooling improve the accuracy of machining

To properly machine a workpiece, to obtain from a formless piece of metal a part exactly as predetermined, in size and surface finish, the required kinematics of machining should at first be ensured, i.e., an ideally accurate mutual movement of the tool and workpiece must be attained.

When manufacturing simple articles, no special problems arise. The workpiece is set on a table or in a chuck, and the tool, cutter or grinding disc is made to move along a strictly defined path, relative to the workpiece, determined by the kinematic components of the machine, i.e., the configuration of its actuating cams, guides, leverages, gear ratios, etc. All this can be easily automated. In accordance with a preset programme, at the required moment, the tool will move to and fro, the number of revolutions will accordingly change, and the workpiece will be moved from one position to another.

However, the possibilities of such a "blind" automatic control system with a rigid programme are limited. It fails to ensure a sufficiently high workpiece accuracy because a rigid programme cannot take into account variable factors affecting the workpiece and the machine such as the non-uniformity of the machining allowance, varying hardness of the material, tool wear, etc. This is why machines are often equipped with active control systems. Special pickups continuously measure the workpiece, and the signals they produce are amplified and fed to the control members of the machine. The machining process stops only when the workpiece has been machined to the required size. Such a system substantially increases the accuracy of machining without changing the rigging and tooling of a machine. This

system is widely used on grinders for machining bearing races, for example, which call for extremely high precision.

It might seem that such a self-adjusting automatic machine correcting its own programme as it operates is the peak of perfection. It is not difficult to see, however, that its possibilities are also limited. There is little harm if a ground workpiece has a diameter slightly larger or smaller than required: this fault can be corrected by simply continuing machining. But what if the axis of the entire surface being worked is offset? This, by the way, is a common fault. Thorough studies in the subject indicate that if a common circular grinding machine is exposed to the sun for two hours, its bed will perceptibly warp with the result that the table will be misaligned by 0.05 mm—a whole 50 microns. Still greater errors are introduced by heated electromotors, bearings and gearboxes. In general, with an increase in finish accuracy, the sensitivity of machines to external influences inevitably grows. These influences include not only temperature fluctuations, but also air humidity, vapours of various chemicals and vibration caused by passing transport. Even magnetic and electric fields or radio waves may affect the accuracy of machining because they adversely influence the operation of the electronic equipment. To eliminate these adverse influences, machines are mounted on elastic base plates, production shops are equipped with thermostats to ensure temperature variations within half a degree, or with air-conditioners. Such a solution complicates the production process, raises the cost of production and is, in the final analysis, the price we pay for the antiquated concepts of classical mechanics. These concepts are based on the behaviour of machines and mechanisms under ideal conditions. According to them, errors and inaccuracies caused by wear, corrosion, thermal and

other strains, that take place, are undesirable and unrequired, and the best way to overcome these difficulties is by properly protecting machines from external influences. From a more up-to-date, cybernetic point of view, errors and inaccuracies are inevitable properties of any real system. Instead of merely disregarding the "primordial" imperfection of mechanisms and discarding all the resulting errors and faults simply as being unnatural, one should find their causes, reveal the sources of adverse influences and study the reaction of machines to these influences. Only then shall we be able to create mechanisms that are capable of successfully performing their functions not only under "ideal conditions", but also in their balanced interaction with the environment. This idea seems promising, for a machine cannot be totally insulated from its environment. No matter how precisely the temperature in the shop is controlled, a machine cannot be insulated from its own internal influences, such as friction between the tool and the workpiece, Joule heat evolved in the electromotor windings, cutting force and other sources of strain. These factors are very important. Observations made on the position of a lathe spindle indicate that immediately after the lathe is started, the spindle begins to shift aside because of the heating of the front part of the headstock, and, 5-7 hours later, its misalignment sometimes reaches 120 microns. It is only after a few hours, when the heat exchange is stabilized, that further displacement discontinues. When work is over and the machine cools down, the spindle slowly returns to its initial position.

How do we get rid of this nuisance? Here we return to the idea of a self-adjusting machine, but this time on a higher level, which means that not only the main working movements, feeding the workpiece and the tool, but also eventual distortions of the machine must be

corrected. It sounds easy in theory, but how can it be done in practice? Even if we incorporate many joints and drives to set every unit of the machine in motion in all directions, it will get us nowhere. Our supercomplex machine would vibrate in operation like a wagon rolling on a cobble-stone pavement. A high-precision machine-tool must first of all be rigid, which means that it must have a cast box bed and a minimum of parts and joints, each moving member being a source of play and errors.

Alexander Pronikov, Rector of the Moscow Aviation Technology Institute, for many years has been occupied with problems of accuracy and reliability of metal-cutting machines. He is the author of a number of inventions, as well as of books and articles on the subject. Being an expert in all the aspects of the problem, he clearly understood that it could not be solved by traditional methods. He proposed a novel, extremely simple, universal and convenient method, applicable to any type of machine and taking care of any combination of deformations (Inventor's Certificate No. 189,281). The essence of this method lies in creating a directed thermal field, i.e., artificially forming and utilizing the thermal strains this far considered to be adverse.

Heating and cooling elements are fixed to structural parts of a machine in any combination that may be appropriate for each particular case. Pickups attached to the spindle, guides and headstock pass signals proportional to the values of the parallel, perpendicular and other misalignments of these parts. Amplified and converted in a simple logic unit, these signals actuate some or other elements. The time of their operation (consequently, the intensity of heating or cooling) is controlled by a timer and is proportional to the pickup signal value. Thus, the machine parts in combination with the pickups, amplifiers and relays constitute a typical cy-

bernetic system. A sufficient number of pickups, heating and cooling elements will effect even the most complex combination of rotary and progressive motions of the respective machine units. The machine, without losing its rigidity and vibration strength, acquires the flexibility and agility of a wriggling snake, and is capable of retaining the right mutual arrangement of all its working members regardless of any external influence, thus ensuring high accuracy of the product.

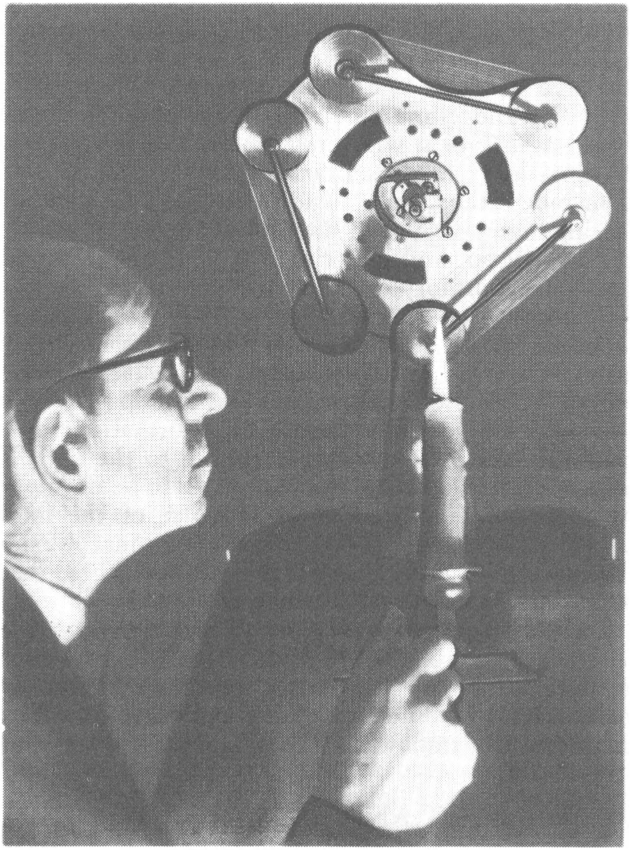
You will not find a "wriggling" machine in the machine-tool laboratory of the Moscow Aviation Technology Institute yet. Instead, you will be shown the first functional model, a rough steel fixture incorporating ceramic electric heating elements and water hoses for cooling. The system works, and the pickups never fail to actuate contacts in response to deformations of the metal structure that are imperceptible to the eye. The idea has become a reality and continues to be developed. The plain and unattractive appearance of the fixture only emphasizes the gist of the inventive concept behind it, as well as its novelty and ingeniousness. These qualities sparkle even without chrome and nickel plating.

Soon, however, an elegant precision machine-tool will replace the rough steel fixture, the water hoses and electric heaters will give way to miniature Peltier thermoelements, which heat or cool depending on the direction of the current flowing through them.

HEATING AND COOLING MIRROR

A thermomilling machine has been invented for machining hot ingots. A cylindrical mirror protects the machine from overheating and prevents cooling of ingots

A few years ago I visited the "Zaporozhstal" Metallurgical works in the Ukraine. First-class works with



Father and son Moslaevs and N. Martjanov have devised a motor which uses metal thermal expansion. It is sufficient to touch it with a palm as the metal disc with three pairs of wire-clad step pulleys starts rotating. Candle flame or a spirit lamp accelerates it up to 400 rpm

plenty of automation. But before rolling process, it was a hitch as the ingots had to be cleaned manually. I saw teams of workers wearing protective goggles who were wheeling heavy barrows along a row of ingots. The wheels of the barrows were sending out cones of sparks. It turned out that the "barrows" were movable grinding machines with fast rotating abrasive discs used to remove surface defects before the ingots were rolled. Obviously, this was hard and harmful work.

Regretfully, the above operation still survives at a number of plants, although it has been strongly condemned both by workers and safety engineers. They are not even pleased when the cleaning is fully done by machines, as at first the ingot has to be cooled and then cleaned. All this takes much time and slackens the production process. The outer crust of the ingot is extremely hard and it is impossible to increase the feed by more than 0.1 mm per revolution with a cutting depth of 2 to 3 mm. Before rolling, ingots must be reheated. This, too, takes much time, especially in the case of high-quality steels with low heat conduction which have to be heated very slowly to avoid cracks from temperature gradients. Incidentally, any overheating, no matter how small it is, has an adverse effect upon such steels.

The best solution would be to clean hot ingots directly without intermediate cooling. How this can be done with a red-hot metal bar weighing several tons? It is even difficult to load it on a machine-tool. Machining hot ingots overheats the working members of the machine-tool and rapidly renders them inoperable. The problem can somehow be solved by means of special protection, by using layers of high-quality heat insulation materials, for example. This approach was chosen by the Italian firm "Innocenti" which at present is the only manufacturer of thermomilling machines. The firm

holds patents in a number of countries (Italian Patent No. 521,174; French Patent No. 1,129,333; United States Patent No. 2,834,259; British Patent No. 773,449) and is exporting its machines to all parts of the world.

The basic heat insulating element of the machine is a double-walled chamber with water circulating inside it. The use of water, however, leads to a number of inconveniences. It absorbs too much heat, so that ingots are cooled too quickly, which necessitates their reheating before rolling. Also, it is extremely difficult to ensure leak-tightness of the chamber, connecting branches and pipelines, and completely rule out leaks under the conditions of substantial thermal deformations and corrosion. Even for a minor repair it is necessary to disconnect a number of joints or almost dismantle the whole machine.

The Soviet Union has not yet produced any thermo-milling machines. At present, there is a great demand for such machines due to the raising of quality standards in metallurgical production.

The designing of this type of a machine was assigned to the Heavy and Special Machine-Tools Design Bureau in Leningrad. As is usually the case, the engineers at the Bureau at first studied patent literature on the subject and then evolved a design of their own (Inventor's Certificate No. 253,541). The underlying principle of the new machine is most ingenious; it combines a highly simple design with improved technological parameters. The most essential element of the invention is a metallic curved mirror of cylindrical form flanking the ingot on three sides and covering the machine. Generally, such mirrors can be seen in "rooms of laugh". Of course, the ingot has nothing to laugh at, but it will be kept warm because the energy it radiates within the visible and infra-red range will be reflected from the mirror and concentrated at its focal point where the in-

got is placed. An ingot weighing 2 to 3 tons will practically not lose heat during machining which only takes 3 to 4 minutes. The cylindrical form of the mirror is selected to give a minimum heating area and reliably protect the machine units from heat radiation. Nevertheless, the mirror is heated to some extent and is prevented from overheating by a flow of air pumped through special labyrinths. Apparently, an air leak is of no consequence, hence, there is no need in air-tight joints.

Alexander Lipilov, one of the inventors and section head at the Leningrad Design Bureau, said that the first experimental model of the new machine would be produced at the Milling Machine-Tool Plant in Gorky. It would then be tested at the "Electrostal" Plant. There, the machine would dress hard-alloy ingots heated in electric furnaces to a temperature of 1200°C, completely removing the defective layer and ensuring optimum thermal conditions for them. This is the only way to speed the process and obtain high-quality materials for essential parts.

MACHINE-TOOL WITH A FLOAT

Mikhail Posolin, a Moscow mechanic, has invented a new thread-cutting machine. In most unyielding materials, a high-precision smooth thread without a single flaw is cut

Almost everyone knows how a thread is cut. It is a simple traditional process mastered long ago. Anyhow, in any textbook on mechanical engineering will be found descriptions of many methods: rolling, turning, vortex milling, tapping, etc. This is not mere theory. All these methods are extensively applied. More often than not, however, threads, especially female, are cut manually. This applies not only to small jobbing shops, but also

to large factories equipped with advanced machinery. The process is easy if the thread diameter is small, not more than 6 to 9 mm. The fitter inserts the tap, screws it into the hole with the screw stock, and a thread is ready. What about a thread of 30 mm in diameter? Ah! This is difficult. How can a torque of 4000 to 5000 kgf/sq.cm be produced manually? Apparently, pipes and crow-bars come to the rescue. Workers use them to extend the arms of the screw stocks. Five or six men put all their weight on the pipes, like barge haulers, to slowly turn one tap.

The greatest trouble is that with every passing year increasing numbers of threads have to be cut in such a primitive way. While triumphantly advancing in all other fields, here mechanization seems to have stopped. Strange as it may seem, it is precisely the technical progress that is to blame for this plight. As machines and mechanisms are designed to stand greater pressures and temperatures, the requirements imposed on threads, especially on their strength, surface finish, sealing qualities, etc., become more stringent.

Mikhail Posolin, a Moscow mechanic and thread-cutter, became interested in the problem. "What's the matter?", he kept asking himself. "A thread seems to be aware of how the tap is turned, by a motor or by hand. There is something mystical about it".

Later it was found that the poor quality of machine-cut threads is due to friction. Let us watch closely how a machine cuts a thread. First, the operator inserts the tap into the cone of the spindle or into a special tap holder. He, then, brings the tap close to the hole and switches on the motor. The tap starts rotating and screwing itself into the hole. Click! The tap now rotates in the opposite direction leaving behind a finished thread. Why is the thread all scratched and torn? M. Posolin found out that was due to the powerful axial force that

pulls the tool back when in operation. Thread cutting is itself difficult, but it is further hampered by additional hundreds of kilograms loading the shank of the tap. At first glance, there is no reason for this load; once you slightly press the handle, the spindle obediently starts moving downward. However, this is only true for an idle stroke. The spindle, in this case, actually slides smoothly through the slot in the bevel gear that actuates it. When it comes to cutting, the tap becomes heavily loaded, the torque presses the spindle against the gear. It is very difficult to displace the two relative to each other. M. Posolin thoroughly studied the problem and found that nothing could be done to eliminate the friction between the two loaded sliding parts. There was only one alternative: either get rid of the load, or the sliding. Load is indispensable in cutting. How about sliding? This can be dealt with easier: it is sufficient to mount an electromotor right on the spindle, couple them directly without any slots or gears, and let them move up and down together as a unit.

While M. Posolin was working on his project, it became known that a Leningrad plant manufacturing equipment for the petrochemical industry, successfully used machines for thread-cutting. A group of specialists was immediately sent there to study the new method. Machines indeed effectively cut threads, but the quality of the latter was far below the required standard.

M. Posolin intensified his efforts. Now that he had integrated the motor with the spindle, he had then to somehow balance the mechanism vertically so that it moved freely. First, he tried a counterpoise, but to no avail: a great force was still required to counter the friction in hinges and pulleys. Finally, M. Posolin suggested that a float be used instead, this being the distinguishing feature of his invention (Inventor's Certificate No. 206,275).

The hollow cast-iron bed of a radial drilling machine was filled with a liquid, which was ordinary water with some anti-fouling additives. A float was linked to the spindle-and-motor unit by means of a metal rod. The buoyancy of the float was selected to match the weight of the spindle-and-motor unit so that the whole system was in equilibrium. Placing a 50-gram packet of tea on the motor housing made the spindle, motor and tool lower at once.

At last the machine was ready. Now the test; Posolin's workmates clustered round the machine. The tap was fixed in the clutch, and a workpiece set on the table. The motor was switched on and the tool made its way through the hole. After a couple of minutes, the thread was finished and meticulously examined by quality inspectors. The thread was impeccable, just right for tight joints subjected to elevated pressures and temperatures. The tap threaded hole after hole and still remained as sharp as ever. Previously, one tap could make 10 holes without sharpening; this time it made 500. The main advantage, however, is not in saving on tools, but in substantially reducing the amount of rejects. Of course, a quality thread cannot be obtained with a blunt tap; but as the durability of a tap is low, it is hard to determine exactly when it becomes blunt, thus producing defective workpieces. Now, this is no longer a problem.

To better illustrate the advantages of the new method, here are some statistics. On the average, thread-cutting accounts for 20 per cent of the total machining process. When threads are cut on a lathe (this method also permits cutting a quality thread, but the fixing and setting of workpieces having shapes other than round is extremely difficult) the thread cutting operation accounts for 30 or 40 per cent of the total lathe machining process. However, skilled turners are not always avail-

able. The new machine makes it possible to thread 100 to 150 holes per shift to the 2nd-grade thread accuracy and 6th-grade surface finish. It can be operated by even low-skilled workers.

LASER AND ELECTRIC SHAVER

Automatic machines which use a light beam to drill ideally smooth burr-free holes and to balance rotors of high-speed machines and various instruments to a pinpoint accuracy

A laser beam can be used to illuminate the Moon, drill aching teeth, establish interstellar communication and measure extremely low speeds, for example, those of continents moving towards one another, initiate and accelerate chemical reactions, obtain 3-D images—holograms, determine stresses in structural elements, transmit energy over long distances, treat skin diseases, boil metal, direct digging machines, coagulate retina, measure cloud thickness and accelerate artificial satellites. However, many of these amazing potentialities for the time being exist in theory, or only in the research laboratories. Has laser technology really in any way contributed to mass production?

With a group of production engineers and foremen, the author recently became acquainted with lasers on display at the Leningrad Scientific and Technological Information Centre.

"And now you will see how easily a laser beam pierces a steel plate", announced the guide as he fixed a small piece of metal in a clamp and pressed a button. A clapping sound was heard, momentarily a bright crimson flame was seen. In the plate there was a hole with torn edges.

Of course, the beam was not properly focused and the mode of operation and the distance to the plate

were selected at random; but even if all the correct conditions had been satisfied, the hole would still have not been perfect. The reason is in the physical nature of the process. When acted upon by a laser beam carrying highly concentrated thermal energy, metal instantaneously boils. The beam burns through the plate in a fraction of a second, but before it is extinguished, it has already spoiled the work by making the walls of the hole irregular. Millions of tiny holes are required for the production of various filters, burners, carburetor jets, wire dawing dies and synthetic fibre spinning jets. It is extremely difficult to drill such holes in unyielding materials. Laser beams can pierce any material but, as we have already seen, the quality of the holes leaves much to be desired. Transverse corrugations are unacceptable for textile workers; bulges and irregularities of the edges increase the hydraulic friction of jets and burners. Without technological improvements, laser drilling is unsuitable for practical use.

A group of engineers at the Moscow Aviation Technology Institute, headed by Assistant Professor Vyacheslav Suminov, started working on such improvements. A special laboratory was set up at the Institute's Instrument Making Department and a powerful laser designed and built by the members of the group. The energy developed by the beam at each burst reached 150 J.

While working on the problem the inventors tried to improve the focusing of the beam and quench it before it spoiled the hole it had made. The attempts were unsuccessful. The holes were bad. The problem could be tackled in different ways. The inventors could try to improve the lasing time control or the rational distribution of the energy over the luminous spot, which as yet is impossible to do, etc. At last, a very simple solution was found.

The piece to be pierced was secured by a nut on the outlet pipe of a compressed air cylinder and attacked by a laser beam. A click was heard, and the air sizzled through the hole. The piece was removed and examined under a microscope. The fused edges of the hole were very precise and smooth like glass. This would have seemed impossible to anyone with a knowledge of lasers. Indeed, it seemed impossible that a mere 50 atm pressure and some cold air on one side of the piece could in a split second raise the pressure to several thousand atmospheres and make the metal boil like water on the other side of it. Yet, this was a hard fact. The holes were perfect, and though the physics of the process was still not clear, the inventors were granted Inventor's Certificate (No. 189,083). Another difficulty appeared; the counterflow of air splashed the lens focusing the laser beam with atomized melt. In order not to change the lens after each burst, it was screened with a glass plate which soon became opaque. Again air was used to solve the problem. A tiny stream of air blowing continuously from a miniature jet onto the workpiece and the lens solved the problem completely.

A semiautomatic laser device designed on the basis of this invention was displayed at the Exhibition of Economic Achievements of the USSR and was awarded two diplomas, one silver and two bronze medals. The device burns 60 holes per minute with a diameter of 0.01 to 0.5 mm through any material up to 1 mm thick. The surface finish obtained is of the 8th to 10th grade. To readjust the device to another diameter, it is enough to change the lens and refocus the beam. A built-in microscope permits of controlling the quality of the holes being made during the process. The rotation of the coordinate table holding a workpiece, the actuation of the laser generator and synchronization of all these processes as well as switching off the device on comple-

tion of a cycle are automated. To make the semiautomatic device fully automatic, it only has to be provided with a storage bin or a workpiece feeder.

Another problem solved by the same group of inventors is balancing. Modern machines and instruments, from gigantic steam turbines and electromotors to electric shavers, are full of rotating parts. The axis of rotation of each such part must pass through its centre of gravity and coincide with the principal axis of inertia, otherwise a considerable centrifugal force will cause vibrations which will wreck bearings and put the machine out of action.

Prior to assembly, a finished part from the production line has to be balanced. An operator fixes it in the balancing machine and spins it. It is out of balance! The operator marks the spot where some metal is to be removed. Now he puts the part under the drill... A slight touch, and the part is balanced again. Too much removed, and the operator has to remove a tiny amount of metal from another place. Little wonder that errors often occur when only milligrams of metal are to be removed. An experienced worker guided by nothing but intuition spends about half an hour to balance a single part. If he is unlucky, he may spend the whole shift working on one part. This is why engineers have been trying so hard to mechanize the balancing process. Attempts were made to remove metal by the electric spark, but heavy currents often caused irreparable damage to parts. If a part is made of ceramics or other nonconducting material, this method is of no use at all.

The newly invented laser apparatus (Inventor's Certificate No. 190,641) cuts down balancing time to 1-2 minutes. The apparatus comprises a balancing machine, two lasers, a synchronizer and a light pulse power regulator. When a part is set in rotation, the indicator unit immediately locates the point of unbalance. The

power regulator meters the right amount of energy, and, at the right moment, the synchronizer flashes out two laser beams which evaporate the right amount of metal.

If the unbalance is not eliminated accurately enough, another flash follows, and another, until full balance is achieved.

This laser device is intended to balance rotors of gyros, electric shavers and other small-size appliances. The capacity of the existing lasers is, of course, insufficient for the balancing of heavy rotors of steam and gas turbines, though the idea is tempting. At turbine manufacturing plants, there were cases when target figures were not met because even the local master had failed to balance a rotor in time. It is evident that a turbine cannot leave the production line without a rotor.

The use of lasers in industry is certainly not limited to drilling holes and balancing rotating parts. There are laser devices which trim resistors in printed circuits to an accuracy of 0.5 per cent by vaporizing excess material; there are lasers that burn through, in a matter of a few seconds, inches-thick marble and asbestos-cement slabs, cut pieces of pyroceramic, etc.

Of late, laser beams have been used for burning patterns in thin films by using a photonegative as a stencil; the new process yields much better results than photoetching. Laser stamping will soon become a reality when pressure is built up not by an explosive charge or an electric spark but by a "blast of light".

MAGNETIC FIELD ASSEMBLES MACHINES

E. Veretennikov of Kuibyshev has invented a magnetic assembly bench

We often talk of automatic machines, automatic lines and automatic plants.

Just imagine an automatic plant with the incessant flickering of red indicator lights, the thud of huge presses, the grinding sounds of mills and drills cutting unyielding steels. Millions of absolutely identical parts are following one another on countless feed belts stretching along shops with not a soul in sight. These parts have never known the touch of a human hand. Here automation reigns supreme. The situation changes, however, when the flow of parts reaches an assembly shop. Such a shop is unthinkable without workers. Complex assembly operations stubbornly resist automation, so you must roll up your sleeves and use your hands to screw down oil-stained bolts and nuts being very careful lest barbs of metal bite into your skin. The work in an assembly shop is hard and demands high skill.

E. Veretennikov, Candidate of Technical Sciences and lecturer at the Kuibyshev Industrial Institute, kept wondering about this paradox each time he visited a plant. Is it unavoidable that parts made by ingenious automatic machines have to be joined together by hand? Assembly has become the stumbling block of the production process and seriously impedes automation. This is explained by the utmost complexity in the automation of the assembling process. The trouble is that each particular machine produces a certain type of parts, whereas assembly involves tens and even hundreds of very different components. A tailor first pins together parts of a suit and fits them on a client; only after that does he sew them together on a sewing machine. Similarly, a fitter, during assembly, has to hold parts of a unit in a required position by various means before he finally screws them together. Sometimes he does it by means of a solid oil-graphite grease which glues parts together; he also uses clamps, straps and holders or even ordinary strings, laces and plastic tapes. If components are big and heavy, they may be slightly welded together prior

to assembly. Of course, the grease, strings and weld metal have finally to be removed. All this makes the assembly process very complicated and seriously handicaps automation.

E. Veretennikov set himself the task of temporarily fixing parts of a unit together without any fixtures or glues. Paradoxically, he meant to fix them without fixing. At first sight, this task seems impossible, but the solution was quite simple. The inventor decided to use magnetic forces, as these are used in the assembly of drilling machine units, for example.

From a special feed bin, cylindrical rollers are carried continuously on a conveying trough. Passing by the poles of an electromagnet, they are magnetized and stick fast to the main part, the shaft. When all the rollers are in place, a "mechanical hand" provides them with a cover from the top. Now the rollers cannot fall out and may be demagnetized.

Needle bearings and other engine units are similarly assembled at the Yaroslavl Truck Plant.

For this original work the inventor has been granted an Inventor's Certificate (No. 132,044). He has named it "magnetic assembly process". Complete as it may seem, this method has a serious drawback: it is only applicable to ferrous materials. What happens with parts made of brass and zinc instead of steel and cast-iron? Can the magnetic assembly method be employed in this case?

Do you know how doctors remove specks of metal that get into the eye? They bring a powerful electromagnet close to the eye and the speck is immediately attracted to it. If the speck happens to be of a non-magnetic matter, alternating current is passed through the solenoid of the magnet. Eddy currents appear in the speck, a magnetic field is set up and the speck sticks to the electromagnet. Why not use this method for

assembly? It is sufficient to replace direct current by alternating for non-magnetic parts to acquire magnetic properties. It is exactly this principle that underlies an invention of A. Ghirel and N. Karelin (Inventor's Certificate No. 241,939). To intensify magnetic forces, the inventors recommend that ferromagnetic sleeves be fitted on non-magnetic parts.

Magnetic assembly opens the way for automatic assembly benches. In this age of automation, the magnetic assembly method will find wide application, primarily at bearing automatic plants where it will radically improve and simplify many technological operations and raise the reliability of the production facilities.

CONTINUOUS CASTING OF ROUND HOLLOW STEEL PIPES

A new machine developed by the All-Union Metallurgical Engineering Scientific Research Institute revolutionizes seamless pipe production

"Do come, please. We start casting at two o'clock". That was the long-expected invitation by Chief Designer A. Charny of the All-Union Metallurgical Engineering Scientific Research Institute.

... From the design bureau, we go straight to the shop.

The experimental shop is almost as big as at an industrial enterprise, but here it is only a small part of the Institute's enormous experimental and production complex. It would certainly make many plant managers envious.

The foundry is already full of people. They are finally checking the mechanisms, coolant supply and electric circuits. Charny dons a beret to protect his hair against sparks, climbs onto the "captain's bridge" and

assumes command. At the same time he somehow manages to explain things to me.

"Our semicontinuous caster is simple in design. Its main component is the crystallizer, a thick-walled copper cylinder about one metre long. Ducts are drilled in it for cooling water, while the melt is fed from above. Mounted under the crystallizer are aluminium baffles a metre and a half long for the aftercooling of the ingot. As soon as the ingot solidifies and reaches the bottom, a hydraulic working cylinder pushes the baffles open and the ingot is placed on the roller conveyer. From there it goes to the pipe mill, then for finishing.

At present, we cast ingots semicontinuously. This is only because it's an experimental plant. As a matter of fact, there is no reason why we can't make the process continuous. Of course, the plant will be larger, but not much. Our caster differs from those used in metallurgy only in the shape of the crystallizer. Ours is round and, mind you, the ingot also comes out round. Oh yes, there's another difference, do you see that additional crystallizer inside? It's a mandrel which makes a round cavity inside the ingot. This is very important!"

The founder standing by the electric furnace gives a signal. Everything is ready. The sparking melt is poured into the teapot ladle. An overhead crane carries it to the filling hole.

I climb up iron stairs leading to a structure nearby. From a height of 3 or 4 metres, I can clearly see the dazzling white-hot stream of metal rushing down into the crystallizer. Whatever is happening inside is a mystery to me: one cannot make a casting machine transparent. In a minute, the entangled pipework at the bottom of the plant is aglow, and out crawls the ingot, a 300 mm-thick spaghetti. A dense grid of fine ribs makes it look like a wafer.

Finally, there appears the upper end with an orifice, and the ingot stops. The sizzling of cooling water jets suddenly ceases. All becomes quiet.

"That's it", says Charny. He shoves the beret back into his pocket. "That's all".

We leave the shop. It is hard to believe that this routine production process has been seen by only a few dozens of people in the whole world. But really this was not a routine procedure, it was an achievement that would go down in the history of technology.

The gist of it can be expressed in one sentence: a process of continuous casting of round steel hollow billets has been developed. Every word in this sentence is full of profound meaning, every definition implies saving of millions of roubles.

Pipes and hollow blanks were cast before, but they were of cast-iron. Seamless ingots were made of steel as well, but only of a rectangular or square cross section. Seamless hollow round steel ingots have never been produced before although they were extremely necessary.

Such ingots serve as blanks in the manufacture of large-diameter sleeves, wheels for railroad vehicles, and, above all, seamless pipes. No matter how much we talk about the ever increasing skill of welders, no matter how many machines for spiral-seam welding of pipes from steel strips are manufactured, welded pipes cannot rival seamless ones. By the smoothness of their inner surface free of burrs, by their corrosion resistance and fatigue strength due to the absence of internal stresses, by their resistance to thermal shocks and creep at elevated temperatures, seamless pipes are beyond comparison.

Suffice it to say that steam mains at big thermal and nuclear power stations with high steam parameters, as well as critical units and pipelines of petrochemical

equipment may be made, in compliance with the specifications, only of seamless pipes. According to some sources abroad, most break-downs and failures in American spacecraft were due to nothing else but the use of welded pipes.

About 10 per cent of the total amount of steel produced in the USSR goes for the manufacture of pipes, half of them being seamless. The target for 1975 is about 8 million tons, which will require 11.5 million tons of blanks. The cost of producing a blank constitutes 80 per cent of the total cost of the pipe. Such a high cost is accounted for by an extremely involved manufacturing process which has strongly resisted improvement over the past decades.

Indeed, the traditional transformation of liquid steel melt into a thick-walled hollow blank which is then passed to a pipe mill for finishing can be compared to a steeple-chase; this will hardly be an overstatement.

First, rectangular ingots are cast. (Round ingots are hard to cast: they are too rigid and, when cooled, they shrink and often break. This hurdle was cleared by making ingots quasiround or polyhedral in shape.) Such ingots are then compressed in a blooming mill into square blooms. These are then fed to a heating furnace and further to a billet mill for rounding. The round billets are returned to the furnace, after which broaching takes place.

This operation deserves to be dwelt on in greater detail. First of all, some high-alloy steels cannot be broached at all, but since pipes made of these particular steels are indispensable, they are drilled for hours and even days with gun-boring drills. Even if it was somehow possible to broach these pipes, the inner and outer surfaces of the broached sleeves are affected with scabs, cracks and fissures which remain on the finished

pipes. Such pipes are not fit for use in important units. To avoid such flaws, special requirements are imposed on the material of the blank. These, however, are often too stringent to be practicable, especially, from the technologists' point of view. Then, if at best, broaching has been done properly, the walls of the blank will have an irregular thickness, the irregularity at times reaching 25 per cent. During pressing, it increases in proportion to the square of the blank's length. Therefore, blanks have to be made short, then additionally machined. This substantially complicates the production process and raises its cost, not to mention the after-treatment which involves scaling and other losses of metal amounting to 35 per cent. That means, only 600 to 650 kg of pipes are produced from a ton of liquid steel.

Casting of hollow blanks rids us once and for all of broaching. Why, then, did nobody try it before? In fact, attempts were made many times but without success, so metallurgists came to regard the problem as insoluble. The reason being that steel, unlike cast-iron, undergoes considerable volume shrinkage during crystallization. A crust of metal envelops the surface of the mandrel and hampers the advance of the ingot; adverse shrinking conditions cause the ingot to crack. Incidentally, this is happened many times when inventors tried to solve this problem. Molten metal would rush through cracks into the blank cavity and encounter streams of cooling water; an explosion would tear the whole plant to pieces.

Recently, a group of scientists from the All-Union Metallurgical Engineering Scientific Research Institute and their colleagues at the Central Scientific Research Institute of Ferrous Metallurgy N. Molochnikov and V. Rutes [Des. Sc. (Tech)], A. Tselikov and V. Gankin [Cands. Sc. (Tech.)] and engineers S. Reznikov, V. Vdovin and V. Sirota developed a number of original

devices extending the scope of physical action on crystallizing metal and eliminating the above obstacle; thus, a semicontinuous caster of hollow steel blanks has come into being.

The principle of its operation was briefly explained at the beginning of this paragraph. Just a few more details to make the picture complete. The filling machine, for example, is not stationary as it should be, but rotates slowly so that the stream of molten metal evenly washes the crust growing in the crystallizer.

The crystallizer itself is not of a conventional type. Apart from forming the outer portion of the ingot, it also serves as an inductor of the rotary electromagnetic field which continuously stirs the molten metal in the core of the ingot making it spin. The principle of its operation resembles that of a squirrel-cage induction motor in which the rotor is replaced by the liquid melt. Spinning, or stirring, makes the metal structure finer, reduces the columnar crystal zone, and practically eliminates axial porosity. This enhances both the mechanical properties and the workability of the metal in hot state.

The mandrel, however, continued to be the stumbling block. Yet, this obstacle, too, was overcome by perfecting its profile and cooperating units and parts. It is too early, however, to discuss this ingenious solution in detail.

This also applies to the effectiveness of the ingot aftercooling system. Masterfully designed, it rules out any possibility of the melt breaking through to come in contact with the cooling water and eliminates the danger of an explosion.

At present, the plant makes hollow blanks with an outer diameter of 260 to 265 mm and an inner diameter of 90 mm. These dimensions were not chosen at random; they suit perfectly the equipment at the Nikopol Pipe

Metallurgical Works where the blanks are rolled or pressed into ready pipes. The length of the ingots is 4 m. Longer ingots would simply find no room in the experimental shop of the All-Union Metallurgical Engineering Scientific Research Institute. Having a total weight of 32 tons, the plant is expected to produce ingots at a rate of up to 1.5 m/min. So far, the rate is slightly less and depends on the type of steel, intensity of cooling and other factors. If an ingot is rolled into a pipe of 325 mm in diameter with a wall thickness of 8 mm, it will be 25 metres long. Such experimental rolling was performed at the Nikopol Works. The output of high quality pipes was almost 100 per cent, a spectacular achievement. For those concerned this figure also means an increase in the annual output of high-quality rolled pipes by 15 to 20 per cent (as compared, for example, to centrifugal casting). On the national scale, it will save several hundred thousand tons of metal a year. A very important feature resulting from the novel method is that the inner surface of the pipes, where destruction usually starts, was practically free of flaws. That promises great savings for the users, since it means longer service life of petrochemical equipment, lower hydraulic friction in pipelines, etc.

The experimental data obtained in this field have made it possible to start designing industrial casters with an annual output of several hundred thousand tons of blanks. These casters will be used at a number of plants throughout the country.

WALKING THERMOPRESS

Yury Menshikov from Alexandrov, a town near Moscow, invented a new thermopress. Its working stroke is a sum of microscopic thermal strains and the pressing force it develops is practically limitless

Alexandrov is a small town about 113 kilometres from Moscow. Located here is the All-Union Scientific Research Institute of Mineral Synthesis.

The main object of research at the Institute is methods of growing crystals of diamond and pure quartz. At the same time, the Institute has the task of developing appropriate equipment which is designed at a special designing bureau.

As is well known, the synthesis of diamond crystals is effected at elevated temperatures and under high pressures. These pressures are built up by means of powerful presses. So it is only natural that Yury Menshikov, the Institute's leading designer, has been working on presses. In his opinion, the presses currently in use suffer from a number of disadvantages that can be eliminated.

The press invented by Yu. Menshikov (Inventor's Certificate No. 264,900) operates on the principle of thermal expansion. The maximum pressing force is practically unlimited (hundreds of thousands of tons) and is only limited by the ultimate strength of its columns and cross-heads. The working stroke and operating rate can be not less than those of a hydraulic press. All this can be achieved by much simpler, therefore, cheaper and more reliable means.

In fact, Menshikov's press is devoid of powerful pumps, cyclopean hydraulic cylinders, high-pressure pipelines and tricky seals. The thermopress rests on a stationary cross-piece, a massive steel or cast-iron plate placed on a bedding. Fitted into this plate are the bottom ends of all the vertical columns circumferentially arranged at equal intervals. The opposite ends of the columns are fitted into the upper cross-heads, two movable steel plates arranged one above the other. The upper ends are fitted into the cross-heads alternately, that is one column, for example, is clamped by the

lower plate, while another passes freely through it but is clamped by the upper plate, etc., to form a chess-board pattern. Passed through the movable cross-heads along the central axis is the press rod, a robust cylindrical bar transmitting pressure to the mould which accommodates a blank.

To start moulding, the press rod is lowered onto the mould and both groups of columns are heated. Then, the press rod is clamped by the upper movable cross-head, and only those columns are cooled which are coupled to this particular cross-head. Naturally, the columns slightly shrink and the press rod is displaced downwards. After this, it is released by the upper cross-head to be clamped by the lower one, and the other group of columns, the shorter one, starts to be cooled. In this fashion, by alternately cooling and heating the columns, hence, by clamping and releasing, the press rod is moved slowly downwards in tiny strokes (2 to 3 mm).

A few words about the columns. They are hollow pipes enclosed in thin-walled casings. By feeding alternately hot and cold water into the pipe and into the space between the pipe and the casing, the column may be rapidly heated and cooled. This is very important because the operating rate of the thermopress depends precisely on this. According to the inventor's calculations, each stroke will take no more than 10 to 15 s. If the columns are made to operate on the principle of "thermal pipes" in which heat is transferred by a periodically evaporated and condensed fluid, the duration of a cycle or stroke may be reduced still more. And, finally, if we are not pressed for time, the columns may be heated electrically by passing current therethrough and cooled by surrounding air. In this case, cooling water is no longer necessary and corrosion is avoided.

As regards the clamps provided in the movable cross-heads, in the first version of the press they were

made as collets with hydraulic cylinders. Evidently, it is no problem to make them operate by thermal expansion and, consequently, to make them grip and release the press rod. Then, the thermopress will be simplified and free of any moving member with the exception of the press rod.

The new press may be used for the synthesis of diamonds and other crystals, when high pressures are needed for a long time; it may be also used for high pressure research work, when the press is only occasionally needed and the use of a hydraulic press is uneconomical, etc.

Incidentally, Menshikov's press has another interesting feature that hydraulic presses do not possess. Its press rod can move upwards, which means that the press will make a perfect superpower jack to be used in the erection of heaviest structures. Unlike a hydraulic jack, it does not need accurately machined components; there is no fear of fluid leaking through seals, so no periodic checks under load are required.

8. Machines of Tomorrow

There is a number of interesting technical ideas. Theoretically, these ideas are well-founded. Not a single patent examiner signing a notice of allowance for appropriate certificate or patent will cast any doubt on the invention utility and feasibility in principle. We say in principle because their realization often takes many years of designing and engineering efforts. As a rule, these ideas are highly promising. Just because of their novelty, they sharply differ from known techniques and their realization calls for the use of radically new equipment and technological processes. In short, they may be compared to the riches of a virgin land.

BEAMS MAKE PATTERNS

In Leningrad an automatic laser beam device has been designed that cuts out materials to patterns

To make a suit or dress, a tailor first measures his customer, then uses the measurements to draw and cut out patterns of the required size. A time-consuming and laborious process. Because of this, the customer has to pay a substantial price and wait some time for the order to be fulfilled.

If yours is a standard figure, why should you go to a tailor? Buy a ready-made suit made at a clothes factory equipped with up-to-date machinery. People there do not take measurements and work out patterns. They are already made for all sizes, for people with more or less standard figures. These patterns are used to cut out material, and the pieces are then passed on to the sewing shop. Instead of using scissors, the cutting-out is done on special cutting machines that handle 30 to 40 layers of material at a time.

In short, full mechanization has been achieved, or rather almost full because the pile of material still has to be fed under the cutter manually, which is most inconvenient. This gives rise to safety problems and calls for increasing the allowance for faults which are rather frequent, and the productivity declines. This is a reason why textile engineers have long been trying to mechanize this operation as well (after all, if gas cutters automatically cut out "patterns" from metal sheets for ship hulls or chemical appartus to a preset programme, why then is it impossible to fully mechanize material cutting?). The nut, however, was hard to crack. Unlike metal, textile fabrics easily crumple and creep, so no mechanical tool is capable of cutting them precisely according to a preset pattern; the process is further complicated by the sharp angles which are unavoidable in such type of patterns.

What is actually needed is a tool that could cleave material without touching it. Such a tool exists. It is a laser beam. When focused on a fabric, it burns a fine, accurate slit; no mechanical pressure is exerted, so no shifting takes place. The contour may be as intricate as any fashion designer could imagine. The light beam having no inertia, can easily carve any pattern.

So far we have only spoken about the underlying idea. As far as its embodiment is concerned, it took

three long years of hard work by specialists in different fields. Under the guidance of Prof. K. Krylov and assistant Prof. G. Zhadzshisky, the action of a laser beam upon different textile materials was studied by postgraduates V. Teplyakov-Mikhailov of the Leningrad Institute of Textile and Light Industry and M. Bogdanov of the Leningrad Institute of Fine Mechanics and Optics. Having obtained positive results, they signed a contract with "Lenglavshveiprom" (Leningrad Board of Clothing Industry), and produced an experimental apparatus for programmed cutting.

The apparatus comprises a cutting table, 3.5 by 1.5 m, made of silumin plates which are highly reflective to laser beams. Placed along the longer sides of the table are toothed racks used for guiding a miniature gantry on which a carriage with a focusing lens slides.

All the motions are effected by step-by-step motors. By sending an appropriate train of pulses to these motors according to a preset programme, the optical axis of the lens may be directed to freely describe curves over the table, so that the beam passing there burns through the stack of material following these curves.

Since the continuous-wave gas laser used in the apparatus is cumbersome (it consists of a high-voltage transformer, a preevacuation pump, a pipe, and a gas mixture bottle, so there is no room for it on the carriage), the inventors decided to place the laser under the table and direct its beam upward. This has been done by means of a number of mirrors arranged in such a way that, regardless of the position and motion of the gantry and carriage, the beam falls directly on the lens.

It is fascinating to watch the apparatus in operation. In silence which is only disturbed by the snuffling of the pump and the drone of the electromotor, a scarlet speck skims over the cutting table. It easily cuts through

a thick stack of material, leaving behind a smouldering narrow slit. Curiously enough, it reminds one of a figure skater making intricate patterns on ice.

The red speck is the burning fabric; as the laser beam is infra-red, it is invisible. Because of this, the focusing lens is not made of glass, but of a mixture of potassium bromide and sodium chloride.

With a cutting speed of 20 centimetres per second achieved this far, one laser apparatus does the job of several workers. Since two and even three such apparatus can be mounted in parallel with only one operator to service them, he will practically replace all workers normally doing cutting at any clothing factory.

However, the lion's share of the gain offered by the new method is the saving of material and not cutting down the labour costs. With the old method, 10 per cent of all the material is wasted because manual cutting needs substantial turning allowance. The laser would reduce these losses by half. The cut itself is of higher quality because the burning prevents the edge of the material from fraying. The edge becomes sort of "hemmed".

Even this is not the main point. A laser cutter combined with advanced computer equipment will radically change the entire sewing technology. Clothing factories will be able to immediately adjust themselves to the latest fashions and produce cheap made-to-measure clothes to satisfy any individual customer.

At present, changing over to a new style means making new patterns, which clothing factories are reluctant to do, to say nothing of turning out clothes made to measure. A laser cutter does not need any patterns. All it needs is a set of programmes which a computer can correct to suit every individual customer.

In his "Memoirs of a Metallurgist", Academician M. Pavlov writes about his student years at the St.

Petersburg Mining Institute and recalls among other things a professor who taught descriptive geometry. Students gossipped that the dry old stick himself cut patterns for his beautiful wife's dresses by using mathematical formulas. Today this is no longer a ridiculous freak but a very simple task easily solved by an ordinary computer fed with an appropriate programme and measurements of the individual customer.

Incidentally, are measures so important that one cannot do without them? There is a story about Tsar Nicholas II who, during a trip to the Ukraine, wanted to have a full-dress coat of a regiment quartered there. The local secret police, scared by the activities of the "Narodnaya Volya" revolutionaries would not allow a local tailor to measure His Majesty. The poor man was only allowed to look at the Tsar as the latter walked in the park.

The tailor did a wonderful job, just as always. Today, remote measuring is just as effectively done by the stereophotogrammetrical camera invented by Muscovite I. Indichenko.

Thus, we have all we need to automate clothe making industry. The laser cutter has been a missing link in the long chain of technological evolution. In the near future, the process of making clothes will be like this.

Once a year or every two years (for children, more often), a special stereoscopic camera takes your picture. When you decide to order a suit, a dress or an overcoat, you choose the right material and design from a fashion and material catalogue, then post your 3-dimensional picture and order to the computer centre of the Central Clothing Industry Board. From this information the computers work out the laser cutter programme which is sent by telegraph or teletype to the factory specializing in the kind of clothes you have ordered. The factory

may even be in another town; that need not bother you, for no fitting is necessary; the order will be sent to you by mail. This method will make it possible to reconcile incompatible things, i.e., to provide a wide variety of fashions, made to suit any individual customer and to raise the productivity of clothing factories due to narrow specialization.

One problem still remains: suppose you are not satisfied with the way your order has been fulfilled. Who is to blame? Nobody, because such a situation simply cannot exist: computers make no errors, and their programmes contain the accumulated experience of the most skilled cutters and fashion designers.

MACHINES WITH ULTRAHIGH EFFICIENCY

A new Soviet invention has enabled heat engines to surpass, for the first time in the history of heat engineering, the efficiency of the Carnot cycle. It is now possible to substantially increase the output and efficiency of engines without any rise in working temperatures

There is not a single engine whose efficiency is over 100 per cent. This is an axiom well known by every schoolboy. If it were not so, the energy conservation law would be invalid and inventors would have long ago produced the perpetuum mobile.

What is more, the inexorable laws of thermodynamics are such that not a single heat engine can have an efficiency higher than that of the Carnot cycle which is much lower than 100 per cent. This efficiency, too, is practically unattainable. Even if heat engines were mechanically perfect and did not lose a fraction of energy for friction, for heating the ambient air, etc., you would hardly find a sober-minded engineer wil-

ling to embody the Carnot cycle in metal. For more than a century, inventors of all engines have been using other less efficient cycles, such as the Rankine, Brighton, Diesel, in short, anything but the Carnot cycle. Sadi Carnot, one of the founders of thermodynamics, himself was sceptical about the feasibility of his own cycle. Back in 1824, he wrote in his great work "Reflections on the Motive Force of Fire": "There is no hope of utilizing fully the motive force of a fuel. Attempts to achieve this will do more harm than good if they leave other important factors neglected. Fuel economy is only one of the conditions that heat engines should meet; under many circumstances this condition is but of minor importance and is second to such factors as the engine's reliability, durability, compactness, low installation cost, etc." An engine operating on the Carnot cycle would be marked precisely by these limitations: low power, enormous size and weight. To understand why this is so, let us recall the basic principle of operation of heat engines. This principle resides in that the working substance capable of changing, under the action of heat, its volume or pressure to a considerable extent (usually, such working substances are gases), is sucked into a cylinder, then compressed, heated to expand and execute work, and, finally, cooled and compressed back to the initial state. After that, the whole cycle is repeated in the same sequence.

As a matter of fact, this is the way all heat engines operate, be it an internal combustion engine, a gas or steam turbine, a Wankel rotary engine, a ramjet engine, a steam-piston engine, a Stirling engine, an Ericsson engine, or any other.

The difference between these engines, from the point of view of thermodynamics, is that in some of them heat is supplied with the working substance having a constant volume, i.e., isochorically, while in others, with

the working substance being under constant pressure, i.e., isobarically; these machines also differ in that in some of them the compression and expansion of gas is effected without heat exchange with the surrounding medium, i.e., adiabatically, while in others, this process takes place in the presence of such an exchange, i.e., polytropically, etc.

Without going into the particulars of thermodynamics, we shall only remind the reader that the operating cycle of any heat engine can be graphically represented in coordinates T—S (temperature—entropy). As is well known, the region under the upper cycle lines on these graphs represents the full amount of heat absorbed by the working substance, while the region under the lower lines represents the amount of heat given up by the working substance to the cooler. Thus, the amount of useful work is proportional, on a particular scale, to the shaded area between the upper and lower lines, while the efficiency is equal to the ratio between the regions under these lines. Since the upper temperature limit for any structure is determined by the heat resistance of available materials and the lower temperature cannot be lower than the temperature of the cooler which is normally the ambient air or cooling water, it is only natural that we should compare the cycles within similar temperature intervals. Even a passing glance at these graphs would indicate the advantage of the Carnot cycle over any other cycle.

Unfortunately, this advantage is only found in theory. Honey is sweet, but the bee stings. Once you reconstruct the graphs of the cycles and represent them in coordinates p—V (pressure—volume), you feel the pain of that sting. You see that the average pressure of the Carnot cycle is extremely high, and that from the outset the working substance has to be compressed to a much greater extent than in conventional engines. This

means that a more powerful compressor and a more robust structure are needed; as a result, the engine becomes very heavy and large. It is precisely these factors that render impractical the Carnot cycle which looks so fine in theory.

Those skilled in the art know these considerations only too well. While incessantly modifying the mechanical structure of turbines and engines, improving their kinematics, reliability and durability, engineers still use the same old thermodynamic cycles. After all, what else can be invented in this field, when all the conceivable combinations of isobars, isotherms and adiabats have already been tried?

After graduating from college, Igor Kovtun worked in the engine laboratory of the USSR Academy of Sciences, headed by Academician B. Stechkin, one of the founders of the jet propulsion engine theory. His task was to make a thorough study of the heat cycles elaborated by generations of scientists. Again and again he read carefully the clear-cut formulations of thermodynamic theorems, trying to find a loop-hole in the impregnable granite walls of that formidable fortress. Believe it or not, he did find one! Speaking about attainable efficiencies, engine specialists implicate, as a rule, that the properties of the working substance are invariable during operation. What would happen if we select such gases and mixtures in which reversible chemical reactions take place in the course of a cycle?

The young engineer presented his idea to his chief, Academician Stechkin. The latter was impressed by such an original turn of thought. Psychologically, he was prepared for this: every good engine specialist knows that minor variations of the gas constant with temperature (the real cause of this phenomenon lies in the deviation of the properties of real gases from those

of ideal ones) affect, usually adversely, the efficiency of an engine. True, this can be detected only from highly accurate calculations. It now remained to turn the adverse effect into a useful one and amplify it as many times as possible, which is a traditional engineering approach. One should remember in this connection the electro-erosion treatment suggested by Lazarenko, cavitational burring, corrosion cracking of metals which facilitates milling, etc.

In short, Stechkin approved of the idea, adding that in closed cycles (i.e., in cycles with the same gas continuously circulating through the engine) nothing more could be done but trying to act upon the working substance.

Having been given the blessing, Igor Kovtun busied himself with calculations. First, he worked alone, then two other engineers joined him. These were Anatoly Naumov and Serghei Kosmatov. The three made several interesting inventions "by the tip of a pen", so to speak.

Perhaps, the one closest to realization is the "closed-cycle gas-turbine plant" (Inventor's Certificate No. 166,202). The essence of the invention consists in substituting the traditional working substances, air or an inert gas, with such less common compounds and mixtures as gaseous sulfur or iodine, oxides of nitrogen, aluminium chloride, etc. When compressed in the compressor, the behaviour of these gases practically does not differ from that of air, but when they are heated upstream of the turbine, their molecules dissociate and split into two, three and even four parts. This means that the gas constant, i.e., the product of the volume of one mole of gas by its pressure divided by the absolute temperature, increases two-, three- and fourfold, respectively. It is as if the amount of gas were increased respectively. Accordingly, more gas passes through the turbine, thus its output is raised consider-

ably. This, however, does not take place without losses: dissociation consumes much heat, which has to be additionally supplied to the gas. In return, the power capacity of each portion of the gas increases: first, it consumes more energy, but in the process of recombination it gives up more energy that it consumes. As a result, the useful work during a cycle is substantially intensified. Moreover, when we supply heat to the gas, a major portion of this heat is expended not on heating, but on dissociation, so the gas temperature virtually remains unchanged. Practically, heat is supplied along a curve approaching the isotherm, and the working cycle of the gas turbine becomes still more productive. Thus, its efficiency increases in some duties almost three-fold as compared to a cycle using conventional gases.

Unfortunately, at that time there were very few gas-turbine plants using closed cycle to which the above invention could be applied. One such turbine with an output of 12.5 thousand horse power, manufactured by a Swiss firm, is installed at the Kashirskaya Power Station.

Only now, with the advent of nuclear power engineering, can the invention of Kovtun and his colleagues be actually used on a grand scale. Close-cycle turbines are especially advantageous for use in nuclear power stations as the working substance in these power stations can be a highly radioactive gas passing through the reactor channels after being subjected to neutron irradiation. Thus, the need for a secondary circuit is eliminated. The power plant becomes much cheaper, for it can be made without the low efficiency part which has the maximum thermal resistance. In addition, the nuclear reactor because of various structural limitations develops lower temperatures, than a boiler furnace or a gas turbine combustion chamber. The increase in

the efficiency of a power plant due to the introduction of the heat cycle based on dissociating gases without any increase in temperature is very important. Economically, this may irreversibly turn the scale in favour of cheap gas-turbine plants which some time ago were less efficient than the more expensive steam power plants.

So far, not a single turbine has been manufactured operating on the new principle, but at the Institute of Nuclear Engineering under the Byelorussian Academy of Sciences a series of experiments has been staged proving once again its feasibility. Previously, it was not quite clear if there was enough time for the gas molecules, dashing through a power plant at high speeds, to disintegrate before the turbine wheel. As it turned out, the time was enough for the N_2O_4 gas flowing through a thin tube at a speed of 50 metres per second to change into another gas, NO_2.

As we have already mentioned, Invention No. 166,202 has not yet been embodied in metal. However, the inventors have already spotted some disadvantages in the method and found a way to obviate them. The matter is that the gas constant increases not only during heating from dissociation before reaching the turbine, but also during compression in the compressor. The gas behaves as if it increased in volume, so more work is required to compress it. During the expansion in the turbine, the opposite is true. These circumstances affect the efficiency of the engine to some extent. To eliminate such undesirable phenomena, the entire compression and expansion process must be effected at a constant temperature, that is isothermally. This is what exactly takes place in an external combustion engine, the Stirling engine. It is more convenient, then, to use a dissociating working substance in it, such as aluminium

trichloride or a mixture of methane with carbon dioxide (Inventor's Certificate No. 213,039).

Recent studies conducted abroad indicate that the engine patented by Scottish priest Robert Stirling in 1816 and considered obsolete for more than hundred years is the best power plant for satellites which require a power of as many as three, five or more kilowatts. It should be reminded that the Stirling engine operates in a closed cycle. The working substance is heated through an impermeable metal wall and the engine may use any fuel ranging from uranium to straw, and, what is more, any source of heat, from the sun beams to heat accumulators, filled with a liquid melt of some substance. A small engine has even been designed that is operated by the warmth of man's hands. The Stirling engine is lighter than any turbine or solar battery of the same power and is more reliable in operation, since it is not susceptible to wear and vibration. The latter feature is especially important for satellites.

With so many advantages, the Stirling engine, however, has a drawback: the transfer of heat through the wall makes it impossible to raise the working temperature to over 600 to 700°C. On the other hand, the radiator-cooler unit has to be made hot at the expense of weight for in outer space heat may be abstracted only by way of radiation whose intensity, as the Stefan-Boltzmann law holds, is proportional to the fourth power of the absolute temperature. Confined within narrow temperature limits, the heating cycle of the Stirling engine is not very efficient. This is where dissociation comes in. The ratio between the temperatures of the heater and the cooler being 2:1, dissociation enables the engine power to be increased two- or three-fold and the efficiency, doubled.

This far we have only discussed engines. Chemically reacting working substances may be also used in re-

frigerating plants. So, for example, reactions accompanied by changes in volume, usually taking place during the gasification of carbon, conversion of hydrocarbons, etc., generate cold at practically no cost and the gases that have passed through the refrigerating plant may be reused as in the case with engines (Inventor's Certificate No. 213,042).

Finally, one more, perhaps the most amazing and revolutionary invention. True, it is unlikely to be realized in the near future, but a discovery that may raise the efficiency of a heat engine above that of the Carnot cycle is sure to win the admiration of all who have any idea of thermodynamics. For a heat engineer, this invention is sensational. To anyone interested in inventions, the matter-of-fact description of Inventor's Certificate No. 201, 434 bearing the unassuming title "Method of Operation of Heat Engine" is really "the sun rays wrapped in paper".

In any internal-combustion engine, hydrocarbon fuels such as gasoline, petroleum, alcohol, kerosene or coal dust burn instantaneously, i.e., are fully oxidized with atmospheric oxygen and turn into water and carbon dioxide. This is a usual, natural and long known method. But it is not the only one possible. Why cannot fuel be burnt step by step? For instance, first, by turning carbon into carbonic oxide, then, by turning carbonic oxide into carbon dioxide, while the products of the reactions are alternately heated and cooled, compressed and expanded. In short, why cannot this be effected by making use of the most unusual thermodynamic cycles? At first sight, this seems senseless. No matter how you burn the fuel, at once or step by step, its total calorific capacity remains unchanged. This must be so, otherwise the energy conservation law would not be true. Yet, calculations indicate that from the same amount of fuel we may derive more mechanical energy than we

did in the past. In short, it becomes possible, in principle, to drastically increase the thermal efficiency of heat engines, raise it above the efficiency of the Carnot cycle and bring it up to almost 100 per cent. This, in a nutshell, is the essence of Invention No. 201,434.

Theoretically, such a possibility is explained like this: in this case we deal with discrete processes in which the stage of the chemical energy being converted into heat is fully or partially absent. Therefore, it is not the efficiency of the reversible Carnot cycle that serves as the limit conversion efficiency, but the ratio between the maximum useful work of the chemical reaction and the amount of chemical energy contained in the fuel.

In short, the inventors have proposed to utilize not only thermal energy, but also the chemical potential of the fuel. A striking example of that utilization is furnished by fuel cells possessing very high efficiency. The advantage of the proposed invention over such fuel cells is that it contemplates the use not of oxygen with hydrogen and other expensive gases, but conventional fuels abundant in nature such as coal, oil and natural gas.

As already said, the inventors have found a possibility to increase the efficiency *in principle.* We emphasize this word because practical realization of the invention presents serious difficulties. We are faced, for instance, with the necessity of building absolutely new machines, step-by-step combustion engines, capable of operating at enormous pressure differentials. This is a task not to be fulfilled tomorrow. This problem, however, is of utmost importance, for its solution may increase the efficiency of thermal power stations by at least 50 per cent, or as it is stated in the descriptive part of Inventor's Certificate No. 201,434, "bring it up to 35-50 per cent or more".

LIGHT BEAM SERVES AS A WORKING MEMBER

Recently, the Committee for Inventions and Discoveries under the Council of Ministers of the USSR registered one more discovery, "photohydraulic effect", filed in the State Register under No. 65. This was the culmination of a series of unique experiments devoted to the studies in the interaction of a powerful laser beam with a substance, conducted by Academician A. Prokhorov, Winner of Lenin and Nobel Prizes, and Candidates of Sciences (Phys.-Math.) G. Askarian and G. Shipulo at the Lebedev Institute of Physics of the USSR Academy of Sciences. These studies open the way for the creation of radically new mining machinery, ice breakers and stamping presses

The advent of lasers several years ago brought about an avalanche of inventions and discoveries. Almost every week we learn about some totally new and most unexpected application of laser beams. It may have to do with space communications, dentistry, operations on a living cell, coagulation of retina, or something fantastic such as illumination of the Moon or a suggestion made by geodesists to measure negligible speeds at which continents are believed to move relative to one another. In this connection mention should be also made of laser gyros and lidars, laser guidance devices, geodetic "beam-levels" for digging and mining machines, "multidimensional" photographs, or holograms, determination of cloud height and thickness, laser cinema and TV, superfast computers, etc. Different as they are, all the inventions based on the use of laser beams have one thing in common: they all deal almost exclusively with either transmission and conversion of what may be referred to as weightless and intangible information or pin-point action upon tiny objects such as celles, bacteria

or components of microminiature electronic circuits. In a word, a laser today is part and parcel of weak-current technology. It is a superfine, although not powerful tool of physicists; to use a simile, it is a surgeon's scalpel or a jeweler's pincers, but not a blacksmiths' hammer.

The studies conducted by A. Prokhorov, G. Askarian and G. Shipulo revealed that a laser can also cope with such jobs as stamping metal, crushing rock, cleaning castings and grinding stones. This far it has been believed that work of this kind can only be done by heavy presses or explosives.

In case somebody feels sceptical about it, it should be stated that by the time the experiments started, lasers had become much more powerful than had been predicted. Only five or six years ago, the maximum pulse power of laser emission reached only some one hundred kilowatts, and the continuous emission power was as low as a few thousandths of a watt. Now these figures are millions of times higher. Now, for example, there is a laser with rods made of neodymium-doped glass with a pulse power of 50 million kilowatts, which is almost a hundred times higher than the output of the Dnieper Hydropower Station. Gas lasers operating on a mixture of carbon dioxide, nitrogen and helium have reached an output of 5 kW in the continuous emission mode. As Academician A. Prokhorov sees it, the latter figure may be 20 times higher. Can you imagine a light beam with a continuous output of 100 kW? This means that the power at the "tip" of the beam is sufficient to provide lighting for a whole block of 5-storeyed buildings or keep a large weaving shop in normal operation.

The main thing is that lasers permit of concentrating energy not only in time, but also in space. The energy density may be as high as ten billion kilowatts per square centimetre. Thus, the intensity of light fields

may be as great as that of the electric fields in the nucleus of an atom.

... Once the inventors directed a scarlet laser beam into a vessel filled with water. This produced an explosive clap, and a geyser of water gushed up to the ceiling. The experiment was repeated. There could be no more doubts. Foci of luminous energy interacting with the liquid produced powerful shock waves. This phenomenon was called "photohydraulic effect". During the first experiments, water blew up the vessels in which it was contained and fancifully bent metal plates immersed into it.

This spontaneous explosion had to be studied and adapted for use.

The photohydraulic effect was produced successfully enough with a common ruby laser of medium capacity. Then it was found that if the water was slightly tinted, for instance, light blue by adding blue vitriol to it, the "light explosion" became more intensive. Aerated water "boiled up" easier than ordinary tap water. It has been proved that it is precisely the impurities such as gas bubbles, sand grains and dye particles, that scatter the light and become centres of local heating. Besides, any liquid transparent to natural light becomes opaque to a high-intensity laser beam and avidly absorbs luminous energy.

Such were the first general conclusions made by the experimenters.

Today, we can say with certainty that the possibilities of practical application of the photohydraulic effect in technology are absolutely limitless. A laser beam can replace almost any electric discharge or explosive which is normally used to initiate shock waves in liquids. It should be reminded that even now an electric explosion in liquids has a wide range of applications ranging from crushing stones and stamping large-size parts to

producing microfertilizers. The photohydraulic explosion, however, will cope with absolutely new tasks, for, unlike explosives and electric discharges, light has tremendous advantages over other types of energy. Light can exert a non-contact remote action. It is absolutely sterile, being free of any impurities, such as products of combu :ion of an explosive, or metal particles evaporating from electrodes. Incidentally, electrodes are apt to rapidly disintegrate under the action of elevated temperatures and pressures, whereas explosives have to be replaced after each blast. In our case, there is nothing that can disintegrate; it is easy to make the process continuous and indeed fully automatic. As you know, continuity of production processes is exactly what modern technology is after.

Light can act upon any object enclosed in buildings, tanks and cisterns, through any wall, provided the right wavelength is selected at which it becomes transparent to the light beam. The duration of a light pulse is thousand times shorter than that of an electric discharge, and the entire energy is released in a progressively decreasing volume. This substantially raises the efficiency of the shock action.

To be more specific, light explosions will find extensive application in the near future in various types of metal working from casting to welding or burring.

Casting is a corner-stone of general engineering. The Soviet Union leads the world in mould casting. Numerous foundries, so called "Centrolits", are being built in the country, where use is made of computers and radioactive isotopes. Advanced technology makes it possible to produce castings that require no after-treatment, except, of course, fettling, i.e., cleaning their surface from moulding sand and cinder patches. Cleaning castings is sometimes more difficult than moulding them. Even today at many foundries you can see workers

in protective masks and overalls, sand-blasting rough castings; you can hear the heart-rending noise of rumblers and the rattle of steel and cast-iron balls flying out of shot blasters. This is the way castings are finished. Cleaning, however, takes too much time and is accompanied by clouds of choking dust composed of sand and metal particles. To get rid of the dust, hydraulic cleaning has been introduced lately, wherein castings are exposed to a powerful jet of water gushing out under a pressure of up to 150 atm. There is a still more advanced method of cleaning: underwater lighting, i.e., electric discharges between electrodes immersed in water. Discharges initiate hydraulic shocks and the pressure in the liquid instantaneously jumps to scores of thousands of atmospheres. Equipment using this principle is successfully employed at a number of plants.

Photohydraulic devices seem to be still more effective, since a laser can easily build up a pressure of millions of atmospheres. A light beam can penetrate narrow slits, tiny holes and deep cavities with no room for electrodes, so that these have to be cleaned by hand. Safety engineers will be happy too: a light beam is much safer than high-voltage equipment.

There is another aspect to it, that of durability.

For instance, to protect parts against rust, they are frequently treated with phosphorous compounds, or phosphatized. As a result, a corrosion-proof coating is formed on the metal surface, consisting of compounds of the metal with phosphorus. Attempts have been made to combine electrohydraulic cleaning with phosphatizing by adding phosphorus salts to water. Photohydraulic cleaning promises to be more effective, as in this case the pressure is much higher.

Fatigue of metal is the most frequent cause of failures of high-speed machines, various vibrators and

railroad vehicle springs, which are subjected to heavy recurring loads. Treacherous fatigue cracks appear in most cases near small holes, oil grooves and notches which are apt to attract and concentrate stresses. The best way to strengthen a part is to cold harden its surface by compressing its outer layer and creating compression stresses in it. This is exactly the effect when parts are blasted with cast iron shot or rolled with hard rollers.

More often than not, however, parts are of irregular shapes and the most critical spots, i.e., grooves, holes and narrow slits, cannot be treated by this method. Several years ago B. Kozin, a Soviet inventor, suggested that the surfaces of metal parts be strengthened by being subjected to the action of water jets under a superhigh pressure. Electrohydraulics was also resorted to. In this field, too, lasers will be the most effective, owing to a combination of superhigh pressures and the ability of beams to penetrate into narrow slits and inner cavities.

Welding is the most universal way of joining parts. Lasers have already been used for some time for obtaining superclean welds that chemists need so badly, as well as "knife" edge welds which are very deep and also extremely narrow. Since a laser beam heats only the weld, without affecting the surrounding metal, parts do not warp and their shape remains intact. A way is being opened for the creation of welded structures of the future, which, as Academician B. Paton put it, "present a perfect, harmonious combination of metal and non-metal parts".

The photohydraulic effect makes is possible to develop an entirely new method of welding, laser-explosion welding. An explosion welds very simply: two pieces of metal instantaneously pressed against each other under enormous pressure are joined so fast that

they cannot be torn apart. This far, explosive charges have been used in explosion welding, with the pressure built up in an ordinary explosion reaching 70 thousand atm, but now pressures many times higher are used.

Experts have noticed that an explosion not only welds sheets of metal, but also strengthens and alloys it. A layer of a new alloy appears around the weld. Sometimes even intermetallic compounds are formed, which are chemical compounds rather than alloys. It is advantageous, then, to specially alloy metals with a light explosion. At the same time, one may study the chemical reactions occurring under a high pressure and at low temperatures.

Explosion welding will also help reducing the number of "unweldable" combinations such as copper and gold; silver and steel; steel and nickel, molybdenum, niobium and titanium. The higher the pressure, the easier becomes the task.

The photohydraulic effect will also be instrumental in making parts by compressing metal powders, in building original rolling mills with vibrating rolls, in explosion stamping and in producing cavitational bubbles to remove burrs from hundreds and thousands of small parts at a time.

An ice-breaker has been invented which is capable of crushing ice fields with hydraulic guns. Describing the invention, the authors insisted that no other means, including lasers, can cope with the problem. They are in a way right, because a laser beam is too weak for that. The photohydraulic explosion is, however, especially effective in breaking up surfaces with water-filled cracks. Incidentally, a powerful laser beam passing through a transparent medium sometimes initiates in it an extremely powerful ultrasonic wave, with pressures reaching thousands of atmospheres. Such a wave breaks up glass lenses and mirrors. This has become an obstacle

in the development of high-power laser optics. At present, the destruction of solids by laser beams is carefully studied. Maybe in the future a mining machine will be developed operating on this principle, i.e., using light waves to which a particular rock is transparent.

Shock waves in a liquid are an ideal means for homogenizing emulsions, i.e., for uniformly stirring them. A few electric sparks in milk split the fat contained in it into small and evenly distributed spherules of the same size. Similar problems often arise in chemical, pharmaceutical and perfume industries. A light explosion with its absolute sterility is better suited for the purpose than an electric spark, to say nothing of an explosive charge.

That is not all. Other possible applications of photohydraulics worthy of mention include the generation of superpowerful ultrasonic pulses for sonars and underwater acoustic communication.

Finally, the most practical and fantastic application is the heat treatment of white iron and synthetic creation of supernew stars.

Let us first discuss white iron. In its original state, white iron is used very seldom because it is too brittle. Malleable iron, on the contrary, is viscous as steel. It is malleable iron which is used in the casting of engine housings, press beds and other critical parts. The composition of white iron is similar to that of malleable iron with the difference that carbon in it is chemically bonded with iron to form cementite. Sharp microscopic wedges of cementite account for the brittleness of white iron. In malleable iron, on the other hand, graphite is present in the form of harmless globules.

To turn white iron to malleable iron, it has to be seasoned for days in soaking furnaces, a costly and inconvenient process.

Parts made of white iron may be irradiated with

gamma rays, as has been suggested by a group of inventors at the Baikov Metallurgy Institute under the USSR Academy of Sciences. Under the action of gamma rays, microexplosions, thermal outbursts having a temperature of ten thousand degrees and lasting a few billionths of a second, occur in the crystal lattice. It is precisely these outbursts that make graphite assume its globular shape.

The gamma irradiation lasts only twelve hours instead of several days. If a powerful gamma laser could be created, which, according to recent findings, is quite possible, these hours could be reduced to minutes.

A powerful gamma laser could do a lot more than just blow up graphite particles. Practical metallurgy may work miracles which today only exist in the minds of the most soaring astrophysicists. In the opinion of the eminent Soviet radioastronomer S. Shklovsky, a gamma laser projector with a power of thousand billion kilowatts could explode the stars within a radius of ten light years. This energy is approximately a thousand times greater than the total power produced by our civilization today. The progress of laser technology is spectacular. Who knows, it may not take much time before man have influence upon the stars.

For the time being, the photohydraulic effect may help to create a multitude of machines we need so much.

WALKING MACHINES

Walking mechanisms: unheard-of manoeuvrability and cross-country ability

Modern surface transport is characterized by wheeled vehicles. However, upon looking through patents of many countries, one is struck by a great number of new types of vehicles intended to replace the wheeled ones.

One of the reasons for this is the inadequate cross-country ability of the wheel. Wheeled vehicles usually require specially leveled and hard roads. Indeed, soft wet soil is often an unsurmountable obstacle for a vehicle. The reason is an inadequate distribution of forces transformating the rotary motion of a wheel into the translatory motion of the vehicle. To improve the cross-country ability, its wheels are either fitted with chains or provided with special ground grip tyres.

This, however, is not the only factor that affects the cross-country ability of a wheeled vehicle. By its operating principle, a wheel is a device with a continuous track, i.e., every point on its circumference successively touches the track and its space centrode is a continuous curve. Therefore, while rolling, a wheel must overcome all the accidents of the terrain, which considerably reduces the cross-country ability of the vehicle. A car, for example, cannot practically cope with a steep gradient exceeding one third of the wheel's radius or a deep ditch wider than half the wheel's diameter.

Then, one should not forget about incessant jolts and shocks that shake a vehicle moving across country. We are not speaking now about passenger's comfort, although it is also important. The main danger in driving across rugged country is excessive dynamic loads on the body and engine of a vehicle which are often many times higher than normal static loads.

Thus, the road quality limits the potentialities of wheeled vehicles, restricts the field of their application and substantially reduces their speed. The most natural way of improving the performance of wheeled vehicles seems to have better roads. Roads, however, are not available everywhere and it is not always possible or necessary to build them.

There are, of course, tracked vehicles that carry, so to say, their own roads with them. Their cross-country

ability is much higher than that of wheeled vehicles, but they are much heavier, their resistance to motion is very high, they consume too much power, and they, too, can encounter obstacles they are unable to negotiate.

The ideal way of moving about cross-country is walking. This is how man and beast have roamed from place to place since time immemorial.

A walking device, unlike the wheel, is a system with a discrete track, which interacts with the ground to a much lesser extent than the wheel. The difference between the two becomes more pronounced on soft ground, where a walking device feels much more at home than a wheel. Indeed, a man never "skids"; another example is horses pulling out a car stuck in mud.

The last but not the least advantage of a discrete track lies in that it need not negotiate an obstacle directly. For instance, a ditch or a large stone can be simply stepped over. A walking vehicle will not only replace the wheel in many cases, but will be, under certain circumstances, the only means of transportation possible.

What has been done so far in the development of walking machines? Let us turn our attention once again to patents. There are to be found scores of inventions patented in the USSR and abroad dealing, in one way or another, with walking devices.This is indicative of an intensive activity of inventors in this direction. On the other hand, such an abundance of inventions on paper with not a single operating walking device points to the fact that the problem is much more complex than might seem at first glance; clearly, most inventors, carried away by the ease with which man and animals move on their legs, fail to grasp the problem in its entirety; hence, their approach is too simplified and can solve but some part of that complicated problem.

We have to admit that all rights for the invention of walking as a way of travel are reserved by Nature; this far, man-made walking machines are only a far cry from millions of their counterparts masterfully designed by that brilliant inventor.

The efficiency of a vehicle can be assessed, for example, by its specific power consumption. By this we mean the actual power consumed by the engine per unit weight in moving at a steady speed.

Power expenditures largely depend on the ground properties and the quality of the road. Minimum energy is expended when a wheel moves on a rail (a rail track is the most efficient means of transportation on wheels so far; a wheel on the rail possesses the lowest resistance to motion of all the existing means of locomotion on the ground). In general, the expenditures of energy of a wheeled vehicle while driving along a horizontal section of a track include the energy consumed by defeating the forces of the resistance to the wheel's rolling, friction forces in the transmission and the air resistance. The vehicle's centre of gravity is at a constant distance from the ground over the entire horizontal section.

On the other hand, in the case of a walking or running human being or animal, the centre of gravity of their bodies is continually displaced in the vertical plane. The centre of gravity of man's body, for example, moves along a curve close to a sinusoid, which calls for additional expenditures of energy in lifting the centre of gravity and braking it as it is being lowered. This is exactly why man and animals, as a rule, spend more energy than a wheel, even though less energy is consumed by their interaction with the ground as their track is discrete.

The rolling resistance on rails and hard roads is insignificant; it is lower than the energy consumed by the lifting and lowering of the centre of gravity of a

walking organism, therefore in such conditions, a walking device imitating the limbs of living creatures, is not efficient. It is just the contrary on rough terrain with a high rolling resistance, whereon a decrease in the track length, i.e., diminution of the interaction between the moving body and the ground with the same amount of displacement, gives a substantial gain in the energy consumed by motion. Walking mechanisms also fare better on marshy ground with low adhesive capacity, when wheels are apt to skid. Due to a high suppleness of a limb and its adaptability to the length of a step, the latter may be always selected such that the reaction to the pushing limb be within the friction cone, however narrow that may be. Finally, the discreteness of the track enables walking machines to move on scree which is an insuperable obstacle for wheels.

The task that every specialist working on walking mechanisms should set himself can be defined as follows: the creation of a walking device more efficient than a wheel, without losing the amazing adaptability of living creatures' limbs.

Even if this task is fulfilled but partially, if a man-made walking mechanism only approximates Nature's creations, its field of application will be extremely vast. At present, the only man-made machines of that kind are aircraft, but they consume too much power.

The low efficiency of aircraft is especially manifest in helicopters. While hovering, i.e., while being suspended at zero horizontal speed, it has to expend much energy to support its own weight in the air. At other horizontal speeds, this supporting energy is also still expended to some extent. At the same time, as far as ground vehicles are concerned, their weight is supported directly by the ground; therefore, the specific power consumption in motion is considerably lower.

The main disadvantage of the "gait" of a living

organism is, as has been already mentioned, the waste of energy to raise and lower the body's centre of gravity. Apparently, this can be ruled out in walking mechanisms. A walking mechanism must be designed in such a way that during the time interval when a "limb" is on the ground, the body should advance along a horizontal line. The advance should be as uniform as possible, to avoid power consumption by acceleration and deceleration of the mass of the body.

There are many mechanisms in which the trajectory of one of the points has straight portions with uniform motion along them. The first attempt to use one of such mechanisms in a walking device has been made by P. Chebyshev. His "pedomobile" is a combination of four λ-shaped mechanisms. The trajectory of the lowest supporting point resting on the ground reminds one of the trajectory of a man's foot relative to his body when walking.

P. Chebyshev became the father of a new trend in designing which can be termed as the "trajectorial synthesis of walking mechanisms". In their designs, his followers have tried to reproduce the trajectory of man's foot. They have proposed a number of patterns for effecting such trajectories. Some of them have simply resorted to a rectilinear pattern, while others first selected what they thought to be the optimum trajectory and then synthesized a mechanism moving along that trajectory. For example, American scientist J. Shigley thinks that the best trajectory is an oval composed of two semicircumferences and two straight lines. He has developed a series of mechanisms for walking devices, in particular, a pantograph mechanism.

This trend, however, although making for ideal motion in the walking stage, fails to provide a workable mechanism. The walking devices based on this principle turn out to be cumbersome, multiple-link and with a

kinematic complex structure. When in motion, to defeat the considerable forces of inertia, additional energy is required.

Another serious disadvantage of such a device is its poor adaptability to continually changing road conditions. To successfully move cross-country, a walking device must be capable of substantially varying the length of its step and the spacing between two successive tracks, raising the "limb" high as it is being transferred; all these "on-the-go" adjustments have to be done regardless of the distance between the "limbs" and the body.

These are the properties that limbs of living creatures possess, so it is only natural that another trend in designing walking devices has appeared, which can be described as modeling synthesis, that is reproducing the structure of limbs of some or other animal. The adaptability of such mechanisms to road conditions has proved to be satisfactory, but the relative trajectory of the supporting point is, as a rule, far from ideal. The efficiency of such mechanisms also leaves much to be desired.

Moreover, to simplify the mechanism and its control system, the proposed devices often replicated only part of a limb with less links, kinematic pairs of different types and a lower number of degrees of freedom. These simplified models not only have low efficiency, but also poor adaptability, which makes their use impracticable. If, roughly speaking, a man's booted foot consists of three elements, two ball-and-socket joints and a cylindrical hinge, the "foot" of the walking device designed by S. Muratori of Italy consists of only one hinge. Such simplified structures may only serve as toys or models to solve the simplest problems in the field.

A walking excavator may serve as an example. It

has two legs attached to the sides. An eccentric mechanism or a group of hydraulic jacks advance the legs in the air by the length of one step and set them on the ground, whereby the excavator body slightly rises. As this takes place, the rear portion of the bottom remains on the ground for better stability. Then, another group of hydraulic jacks takes over to draw the body to the legs and seat it on its bottom, the legs then are set free and the cycle is repeated.

Actually, this is crawling rather than walking: this is the way a crocodile crawls, or a scout. It is not the most rational way of travel because the engine has to lift the whole weight of the excavator. This method is not universal and can only be used in low-speed vehicles as is the case with walking excavators.

The search for the most rational design of walking devices is most likely to be pursued in two directions: trajectorial and modeling synthesis. A walking mechanism must have an ideal trajectory of its variable-size supporting point. Besides, this trajectory must cover not just a small region fixed relative to the body of the mechanism, but a whole volume of space.

This problem can be solved with the aid of the contemporary theory of synthesis of mechanisms. It should only be borne in mind that this synthesis is going to proceed along both geometric and dynamic lines. In a uniform motion of the supporting point along an ideal trajectory, other links of the mechanism move, as we have already mentioned, irregularly, causing considerable inertia forces. If an ideal trajectory is not strictly followed, in some mechanisms provision can be made for substantially reducing the non-uniformity of motion of all the links or, at least, of those that have a larger mass. Therefore, for a particular type of mechanism, the parameters may be selected so as to ensure a minimum vector sum of all the motive forces. In

this case, the supporting point will move along a trajectory other than an ideally straight one.

It should be noted that a "foot" moving in the air follows a complex trajectory, as it leaves the ground. For that reason, the reaction of the inertia forces on the body of a walking machine may be considerable. This dynamic reaction is transmitted to the other "feet", forcing their actuating devices to execute extra work. Driving a vehicle using such a mechanism becomes uncomfortable. If the trajectory is ideal, the body moves horizontally and uniformly; this motion does not depend on the accidents of the terrain, so such a vehicle is much more comfortable than a wheeled one.

J. Shigley has proved that to completely defeat the inertial reactions in a "quadruped" vehicle, for example, sixteen identical "limbs" should be provided, properly phased and grouped in fours in each corner of the vehicle. The task may be also set forth as follows: one has to properly select the trajectory of the supporting part and the law of moving along this trajectory and arrange the centres of gravity of the links so as to minimize dynamic reactions.

A walking device has one more feature, or rather limitation, which determines the selection of its structure and which is at the same time irrelevant in wheeled vehicles. This feature is often overlooked by those who invent new walking machines. It is the gait, a manner of walking or moving a foot. A horse, for instance, uses five main gaits (pace, trot, amble, canter, gallop) and some intermediate gaits. The gait affects both the speed and efficiency of travel. However, this is not the only thing that matters.

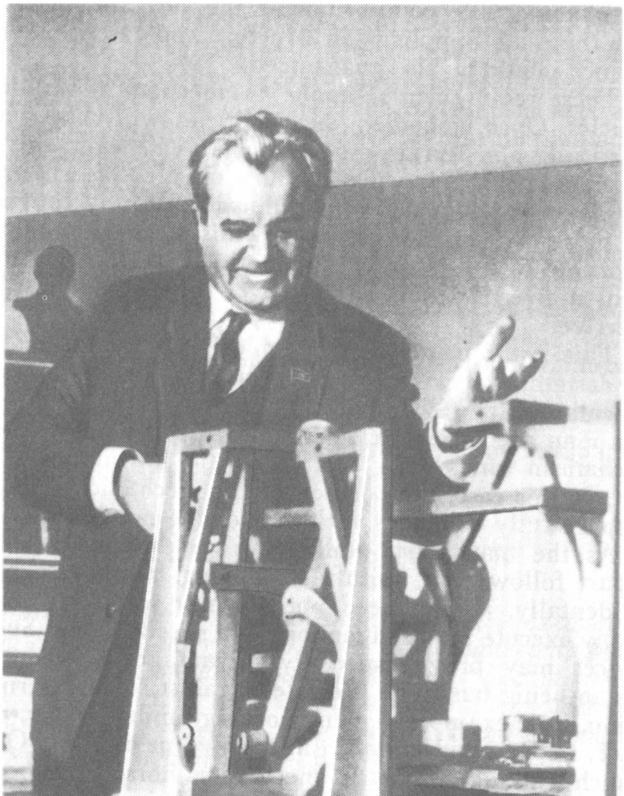
At different moments of time, the number of limbs set apart and their arrangement on the ground are different. The position of the body's centre of gravity relative to the points of support varies continuously as

well. This is what wheeled vehicles do not have, for their centre of gravity is invariable relative to the wheels. To ensure static equilibrium and, hence, the stability of a walking mechanism, the projection of its common centre of gravity on the horizontal plane must be within the polygon whose vertices are the supporting parts of the "feet". Apparently, running animals are not always in the state of static equilibrium. So, in some phases of gallop, for example, a horse has only one of its hind limbs on the ground. Perhaps, this is a state of dynamic equilibrium. As regards such systems, however, these questions still remain unanswered. This is why in developing a walking device, the order of moving its limbs should be such as to ensure static stability of the system at any moment.

In the case of four limbs, for example, the choice of possible combinations of gaits and step lengths is quite limited. In order not to affect the adaptability of a walking system, provision should be made, most probably, for a special automatic device indicating the position of the common centre of gravity relative to the supporting points and preventing the system from assuming such positions that bring about a loss of balance. Such an automatic device may pick up forces in the "feet".

Finally, there still remains the problem of a feedback with the road. The driver of a walking vehicle must "feel" the road better than the driver of a wheeled vehicle. This is mostly due to a much greater freedom of choice as to where to put the limb. Besides, a limb remains in one place longer than a wheel at the same average speed. This is why the stability in "standing" is of great importance to walking machines and the driver should continually receive information about it.

Hence, a practicable walking vehicle must meet the following four requirements: adaptability to variable



Academician Ivan Artobolevsky with P. Chebyshev's "pedomobile"
the prototype of running machines of the future

road conditions; optimum trajectory of supporting parts; continuous stable equilibrium of the system; feedback with the road. Simplicity in structure and ease in maintenance should be also guaranteed.

These requirements apply to mechanical walking vehicles. Once embodied, such vehicles will cope with practically any terrain on which man can walk. But if one registers the kinematic characteristics of a man's feet as he walks, makes a mechanism faithfully copying the movement of the feet, makes this mechanism move according to the recorded kinematic characteristics and sends it after the man, it will cover the distance just as effectively.

This is the principle that underlies a new trend in the designing of what can be termed as "pedipulators". In walking devices designed by such methods, the feet of a man are linked through follow-up systems with a mechanism which is a replica of the kinematics of a foot. In this case, the position of the mechanical "foot" in space fully coincides with that of the man's foot.

As the man starts walking, his mechanical counterpart follows suit, faithfully copying his movements. Incidentally, a man need not actually walk. He may simply execute required motions in a special cabin. Such devices may prove especially advantageous when a human being has to be protected against some external action, for example, when working under water, in space, under irradiation, in aggressive media, etc. One of such walking devices, a "mechanical horse", has been made by American engineers for work in space. It is also a combination of muscles and hydraulic servo-amplifiers. The device is actuated by an operator by changing the position of his feet and hands linked with the respective levers of the device. The man appears to be crawling in the air, while the machine walks and even runs on the ground.

It is characteristic of this trend that the choice of the place to set a foot on, the trajectory and the law of movement of the feet and body relative to the ground, as well as the task of preserving the equilibrium are the prerogative of the operator. The mechanism acts as a power amplifier and furnishes the information about the route and its own position, which the operator needs for effective control of the machine.

Riding such vehicles, however, must be hard work for an operator. As a matter of fact, the whole distance has to be covered by the operator walking or incessantly moving his hands and feet. To do this for a long period of time even without a load is not an easy task.

To sum up, the problem of creating a practicable walking vehicle is very difficult and requires an effort of experts in different fields, mainly in mechanics and theory of mechanisms, as well as in cybernetics, mathematics, biology and medicine.

FORWARD TO "IRON MIKE"

Anthropomorphous mechanisms to replace excavators and cranes. Steel gullivers and lilliputians will build houses and ships, assemble rolling mills and microcircuits. For the first time in history it becomes technically possible to realize the idea of totally blending physical and mental work

Some twenty years ago, unusual mechanisms made an appearance in nuclear research centres. These were rather simple devices, named manipulators, designed to transmit over a distance movements and forces developed by man's hands. Without manipulators, one cannot handle "hot" radioactive substances. As a matter of fact, a manipulator is nothing else than a poker with which

we stir embers; it is used, however, for more delicate operations. So its design and kinematics are more complicated than a poker. In earlier manipulators, the movements of an operator's hands were transmitted through flexible rods and cables to simplest actuators—levers, shears and clamps. The operator himself actuated and controlled these "remote tongs". As years went by, manipulators were modernized and improved, but far more important was the radical, though subconscious, change in the thinking of manipulator experts. The jinn was let out from the bottle. It suddenly became apparent that mechanisms which primarily were assigned secondary tasks could revolutionize technology on an unprecedented scale and substantially raise the productive forces of mankind.

In short, a manipulator is a technical device simulating motor functions of man's arm and hand. Not a single philosopher, furiously arguing that machines will never be able to think will doubt for a moment the possibility of creating an artificial hand as dexterous and nimble as man's.

Nevertheless, it is sometimes easier to model mental processes than to simulate the outwardly simple movements of a hand. At present, specialists do not intend to fully copy an arm with its infinitely rich variety of functions. Suffice it to say that a man's arm has 27 degrees of freedom, a mobility unsurpassed by any mechanism. A complex movement involves scores of joints, ligaments, muscles and tendonds at a time, their action being continuously controlled by the brain through a ramified system of receptors. Even the simplest model of an arm, which is the manipulator of today, is an exceptionally complex spacial mechanism with a host of hinges, kinematic pairs and independently moving links. Anyone who, in his student years, dealt with an elementary calculation of a crank gear mechanism

is sure to see that even the simplest manipulators cannot be designed without resorting to long rows of mathematical formulas abounding in roots and trigonometrical functions, infinite series and integrals.

Of course, we do not in the least doubt that these difficulties can be overcome and that more or less perfect models of an arm can be created. Even today, the best manipulators are almost as agile as a hand in, say, a mitten. Built-in actuators enable a manipulator to develop limitless multi-ton forces. The amplitude of its movement depends only on its size and may be several tens of metres. Visual and tactile feedbacks enable an operator to feel the forces developed by the mechanical arm. This property is inherent, for example, in the manipulator developed at the Institute of Mechanical Engineering. It can be used to effect highly delicate and complex movements.

Much has been written about the employment of manipulators in space, under water, at nuclear power stations and underground, under circumstances when man's life and health are in danger. Widely known are biomanipulatory artificial biocurrent-controlled limbs for disabled persons. Even a possibility has appeared to control the manipulator by the movement of eyeballs. This idea has been elaborated by Estonian scientist A. Lauringson. Oculists have developed reliable methods for following a pivoting eyeball. A signal is produced which is amplified and used in the control circuit. Experiments have shown that an eyeball can pivot at an angular speed of 30 degrees per second and follow an object with high accuracy. As compared to the natural control system, eye-brain-hand, this method has proved to be faster and more accurate. Evidently, it could be advantageously used by astronauts under acceleration conditions when it is extremely difficult to move a limb. The last cry in manipulator engineering

is "Ernst's Hand" developed by a Swiss post-graduate student Heinrich Ernst under the guidance of celebrated cyberneticians Claude Shannon and Marvin Minsky. Equipped with photocells and contact pick-offs and coupled to an electronic computer, "Ernst's Hand" can pick up bricks off the floor and put them in a box.

At Stanford University, a walking, or rather roller-skating, robot-manipulator has been created, an "Iron Mike", to use Norbert Wiener's expression. It has a "moustache", two feelers with which it discerns obstacles, an optical locator with which it determines the distance to a wall, a tele-eye connected to a discriminating computer and a navigation unit laying its course. The Stanford robot can be instructed to go to a particular room and fetch a particular object. If an acoustic system were incorporated into the robot, it would obey oral commands.

Such spectacular "cybernetic wonders" make a lot of publicity, but far more important are real perspectives opened up for technological progress even by "brainless" manipulators capable of nothing else but faithfully simulating and amplifying the movements of a man's hand. Why do scientists take such pains to solve such a simple problem? What do we need such a big and strong hand for? Is it not only a hang-over from the anthropocentric prejudice of two centuries ago, when automata of the future were pictured by many as moving iron puppets? Is a crane or an excavator any worse if its hook or bucket does not look like an over-sized hand?

These questions are not merely rhetorical. Yes, a hook or a bucket is worse than a hand because they are not as versatile. The hand is the only known executive member with an infinite range of functions ranging from playing the piano to loading logs, from painting to handling a pick hammer.

In present-day production, manufactured articles change so rapidly that one has to constantly readjust or even replace the equipment. Man, even an unskilled worker, is the only permanent link between semiautomatic units. Recently, the Americans tried to devise a simplest anthropomorphous robot to handle unskilled work in a production shop. Even the remotest, purely kinematic resemblance to man was sufficient for the machine to manipulate china-ware, spray oil tanks with an air brush and feed workpieces to punching presses.

The main object is high efficiency. Very often it does not depend on swiftness of movements alone, but also on their coordination and precision. Not long ago, an optical lens weighing several tons for a large astronomical telescope had to be loaded on a flat car. It took highly skilled loaders six hours. Gulliver would have managed to load it in a few minutes. This also applies to shops where huge hydraulic turbine or electric generator components are built. Overhead cranes srawl slowly, dragging the steel giant. Finally, the cyclopean shaft comes to a halt over the machine. Now the most important stage begins. Millimetre by millimetre, crane operators slacken out the hoisting cables, riggers shout out commands and gesticulate until the shaft is lowered onto the supports. It takes a turner one second to fix a similar shaft, only a thousand times smaller, in the chuck because he uses his hands and not clumsy cranes.

Imagine now that you have an "ideal manipulator" which is as easy to control as your own hands but which is much more powerful and bigger in size. Science and technology can provide all the necessary means to make such a manipulator possible. It is now the inventors' turn to tackle the problem.

We have already discussed the kinematics of manipulators. The latest achievements in "holovision" can make it possible to reproduce the optical images of a

working station. Feedbacks as perfect as natural ones will make the operator aware not only of the mechanical resistance and weight of the objects he handles, but also of their temperature, the texture of their surface, etc. Actuators will be much like muscles.

Let us take, for example, the "muscle element" invented by McKibbon of the United States. It comprises a thickly braided rubber tube with one end plugged and the other admitting compressed gas. The gas makes the artificial muscle swell, and a force is built up in it. McKibbon's "muscle" is cheap, light and flexible; it develops a force almost proportional to its length, diameter and the pressure of the gas fed into it.

There is another most interesting design of an artificial muscle using the principle of conversion of chemical energy into mechanical. It has been proposed by A. Kachalsky, President of the International Theoretical and Applied Biophysics Organization. His "mechanicochemical" device includes synthetic fibres rapidly and incessantly contracting, depending on the concentration of the solution in which they are dipped. Like a real muscle, the artificial one also uses the chemical energy of the solution. Even in the first experimental model, these fibres were capable of lifting a weight 1000 times heavier than themselves. In conventional lifting mechanisms such a ratio is absolutely inconceivable. True, the efficiency of Kachalsky's muscles is only 10 to 20 per cent, but it can apparently be increased.

We need not be concerned with technicalities, though; instead, let us assume that the "ideal manipulator" has been created. We have already mentioned the dramatic rise in labour productivity which is expected due to the development and increased use of lifting mechanisms. This far, neither the multitude of cranes of various types, rail, bridge, truck, bicycle or gantry, nor tens of thousands of electric hoists, winches,

jibs and jacks, nor a host of lift trucks have been able to radically solve the problem of mechanizing loading operations. Millions of people at freight terminals and goods yards still continue turning crates and rolling barrels, hooking and unhooking cables. The laborious trade of a loader remains one of the most widespread occupations the world over. Practically the same job, only on a more skilled level, is done by assemblers of large machines: walking excavators, rolling mills, steam turbines, bloomings, hydraulic presses, etc. Each component may sometimes weigh tons or even tens of tons, so assembling operations become brain-racking problems requiring high skill and hours of arduous labour. The same holds true for builders of ships, gigantic aircraft and spaceships.

"Ideal manipulators" will even up the score and enable man to look upon cyclopean machines with the eyes of a giant. Owing to the perfection of feedbacks, man will easily get used to the powerful huge paws of the manipulator and regard them as his own hands.

One operator will be able to load and unload, without riggers and slingers, freight cars and ocean liners in a matter of minutes; he will be able to assemble excavators, turbines and hulls weighing thousands of tons and easily manipulate by remote control three-metre long wrenches and parts as big as cars. The might of the steel hands will be combined with mechanisms effecting subconscious control over their movements like those "constructed" by Nature over millions of years of evolution. Just imagine how simple the erection of industrial equipment, maintenance and repair of blast furnaces, chemical reactors, nuclear power stations and power transmission lines will become, when manipulators enable man to handle any component regardless of its size. What is more, steel hands coated with an insulating layer do not fear high voltages or

elevated temperatures, so it will become possible to repair furnaces and power lines while they are in operation.

An old Hollywood science-fiction motion picture featured King Kong, a huge ape crushing sky-scrapers barehanded. Construction sites of the future will be run by homo sapiens doing the opposite. An architect will be both an artist and a building worker. Having drawn a project he will erect by manipulating the knobs of a control panel, fantastic palaces and cosmodromes from prefabricated parts. A sculptor will actually chisel cyclopean statues rivaling the idols of Easter Island in their size. Physical and mental work, artistic ideas and elevated thoughts, masterful work in metal or stone will all blend into a single whole, thanks to "brainless" manipulators that will help man to overcome the resistance of the inert matter. The sculptor, architect or machine builder of the future will be like an artist reviving his visions on canvas by a bold stroke of his brush, or like an electronics engineer impatient to construct a circuit he has just conceived.

Here, a crucial question arises: must the robots of the future resemble man? The answer to this question will in most cases be: yes. As philosophers say: Man is the measure of all things. Man has not only perfectly adapted himself to the environment, but has also adapted to himself "a second nature", the artificially created "technosphere". The controls of all mechanisms, levers and switches, doors and stairs, automobiles and aircraft, are all created by man and for man to fit his size. This is why an anthropomorphous robot will adapt itself faster and more easily to our environment than a robot of any other type. In addition, it is much more pleasant to be in the company of a likeable android, than of an ugly monster. An android will stir up aesthetic emotions which are so welcome in our every-

day life and work. The sight of beautiful things elevates man's spirits. Nobody will kick a beautifully made mechanical doll or strike it on the head with a sledgehammer. People will take extra care in lubricating and adjusting such a machine.

It is also appropriate to point out the advantages of midget manipulators making it possible to transmit movements of human hands to microscalpels, microneedles and microgrips. Micromanipulators provide the unique opportunity to operate on living cells and microorganisms, assemble microcircuits and make automatic laboratories for detecting and studying living matter on other planets.

And, finally, "household robots". Many specialists are unanimous in predicting their appearance in a matter of a few years. Imagine that your kitchen equipment or TV set are out of order. You telephone your service centre, and the technician on duty gets in touch through a telecommunication line with the robot assigned to your apartment block. The robot comes to your place and repairs your things.

In a nutshell, even today, to say nothing of tomorrow, "mechanical hands" permit of mechanizing a number of unique, non-standard and infinitely diverse operations that cannot be adapted to a production line. It is exactly this what makes them so important.

It is difficult to predict when some or other specific type of manipulator or robot will appear, but the amazing theoretical progress attained in this highly promising field allows us to believe that designers and inventors will not keep us waiting for long.

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This book is a review of the 20th-century machines, hundreds of thousands of various machines and mechanisms for moving tremendous masses of earth, for weaving fabrics, for "baking" diamonds and for many other jobs. It tells you about machines which hop around like grasshoppers, about machines which can work for weeks without conventional motors and batteries, and about those that can repair themselves.

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